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AUTOMATIC TRAIN CONTROL.*

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In view of the great awakening of public interest, and especially because of existing laws and the recent action of the Interstate Commerce Commission of the United States, perhaps no time is more opportune than the present to discuss the subject of automatic train control, or as I prefer to call it, auxiliary train control.

More than two years ago Congress approved a bill which, in turning the railroads back to private control, retained for the Commission the mandatory power to order automatic train control whenever in its judgment it was justified in issuing such order.

Despite the fact that the Government took this constructive action, it is to be regretted that the power conferred was limited in character, that is, to the subject of train control, for it ought to cover the subject of safety appliances generally, such as, for example, wayside signals.

Naturally reluctant, despite disregard of recommendations made in various annual reports, to direct the wholesale installation of equipment of this character without further development and knowledge of operation, the coöperation of the railroads was

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invited, to the end that a committee was appointed by the American Railway Association to coöperate with the Bureau of Safety.

Apparently, however, because of slowness of progress and a growing conviction that some act more radically constructive than the deliberations of committees was necessary, the Commission, on January 10, 1922, directed forty-nine railroads to show cause why orders should not be issued to begin and complete, within specified time limits, installations of automatic control on typical railroads, some equipped with wayside signals and others not.

FIG. 1.

Test train on tracks of New York Central.

This order was forward-looking enough to recognize the fact that automatic or auxiliary train control was not necessarily a subordinate attachment to a wayside signal, but that for a great part of the railroad mileage still unprotected by automatic signals it was possible that new developments might make the latter unnecessary.

Public hearings in accordance with the above-mentioned order to show cause were recently held in Washington, at which the railroads concerned, collectively and individually, presented their objections to making it conclusive in the form prescribed; and later, other hearings were held at which to hear those who are devoting themselves to the solution of this problem.

That the final orders of the Commission may be modified is possible, and personally I am of the opinion that some amelioration in the times specified for selection of systems, the beginning of actual installation and the period set for completion of equipment would be in the best interests of the train control art itself, and materially conduce to safety, economy and ultimate permanence. In fact, I have so expressed myself in a brief submitted to the Commission.

On the other hand, in spite of the technical and operating objections which have been raised, it is hardly conceivable that the Commission, acting under the authority of an Act of Congress which has given it the mandatory power to do that which it believes to be in the interest of the safe and efficient operation of railroads, and having arrived at constructive conclusions based upon the accumulated experience of railroad operation, as advised by its responsible experts, will abandon the general conclusions to which it has arrived.[1]

SUMMARY OF OBJECTIONS.

The arguments presented by the railroads at the hearings held in Washington may be briefly summarized as follows: That there is a general objection to third-rail impact systems, and that as regards those which have actually been put in practice many specific troubles have developed which indicate their unreliability; that the experience with non-contact inductive systems is not sufficient to justify final conclusions; that automatic train control should be regarded simply as an adjunct to wayside signals, and therefore not to be considered until the roads are fully equipped with such, and in fact until every contributing cause of accident—including grade crossings—has been removed; that sundry tests of what may be improved systems were either under way or visualized in inventors' minds, which tests might possibly some day

[1] The conclusions reached by the Commission, after full consideration of the various arguments advanced, were formulated in a general order issued under date of June 13, 1922, to the railroads mentioned in its preliminary order. This in the main carries out the original intention—that is, directs that the railroads shall, without unnecessary delay, proceed with the installation on a large scale of automatic train control of some character.

The time of selection of systems, as well as that for completion, was extended six months, and the privilege granted, where divisional installation had already been undertaken, or where there could be a consolidation of tests on divisions using common equipment, to proceed on that basis.

produce something worth consideration; that with regard to even these the railroads hoped that the Commission, even should such tests result entirely satisfactorily as regards operation, would then agree that automatic train control is unnecessary; that an acceptable system should be universally interchangeable; that train control provision would be useless for the regular equipment of a road unless all foreign equipment was likewise protected; that the

FIG. 2.

Section of test track, New York Central.

capacity of a road would be materially restricted; that the cost of equipment and upkeep would be prohibitive; and finally, that poverty, even at a time of coming prosperity, would not warrant any general expenditures for this purpose.

EARLY ATTITUDE.

When the general bill was in conference the statement was made that no automatic control apparatus had been developed that would meet the specifications of the American Railroad Association, and it was doubtful if there ever would be—the opinion being also expressed that "it was an utterly impractical scheme," which would remove the responsibility of handling the train from the engineman.

The same profession of impossibility of engineering accomplishment has steadily opposed every radical improvement in rail-

way equipment and operation; in the face of which the air brake has been developed, the car stove has been discarded, the automatic coupler has been prescribed, the automatic block signal system has been installed, and steel cars are taking the place of wooden ones; while grade crossings, despite the prophecy of bankruptcy by the head of one of the most important roads entering Chicago, have been abolished in that city.

The pronouncement that automatic train control would remove the responsibility from the engineman and be productive of more serious accidents is simply an opinion. It is not supported by experience with the installations already made, whatever their shortcomings, and I believe utterly mistakes the psychology of an engineer operating under a proper system.

On the contrary, I feel certain that automatic train control—not an automatic "stop"—whether used independently or in connection with wayside signals, which are in fact themselves automatic and take the place of direct visual study of track conditions, will not only safeguard trains from collisions in case of inability of the engineer to see, understand and obey his signals, and from dangerous speeds on curves and cross-overs, but will tend to make him even more alert and efficient in his duties than at present.

THE GENERAL SUBJECT.

With the presentation of some lantern slides later, I will briefly touch upon the general subject of automatic train control, state what I believe should be the underlying fundamentals to be followed in its development, and describe something of the Sprague system in its progressive possibilities of application, and especially as illustrated in its most complete form on an installation which for some time has been undergoing intensive tests on the New York Central Railroad.

Much has been heard about the "infancy" of the automatic train control art, of the need still of years of development in "practical" railroad service; and likewise of the perfection of the wayside signal—of its reliability, the infrequency of failure, its importance and necessity as an adjunct to railroad operation, despite the fact that it is used on less than three-tenths of the mileage of the country.

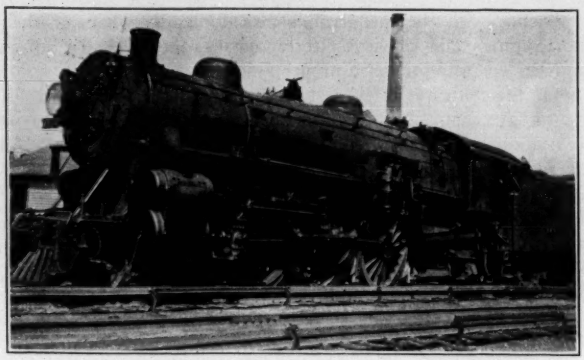
As to the first, I have heard many similar views in the course of the past two-score years, during which period we have seen a

large number of major electrical developments, many of which I have been fortunate enough to be concerned with.

THE WAYSIDE SIGNAL.

As to the wayside signal, heralded as the finality in operative direction, is anything the matter with it, and if so, what? Granting all that may be said of it, why hasn't it stopped railroad collisions? The trouble isn't with the wayside signal itself; but

FIG. 3.



Test engine.

it is nothing more nor less than a limited indication of traffic conditions, and to be effective it must be seen, understood and obeyed by the engineer. The accidents which have occurred cannot, happily, be charged as a rule against failure *per se* of a system which has been elaborated with great skill and at large expense, and has undoubtedly aided materially in increasing the safety and capacity of railroad operation, or to lack of conscientious and able supervision of an intricate system by capable men.

It is the human element necessary to make it effective which fails—oftentimes because of no fault of the engineer but because of climatic or other causes affecting visibility. Even when seen the signal is not always understood, and, as has been well proven, it is not always obeyed even when seen and understood, for causes which, whether mental or physical, are thoroughly well known and

which afford identical reasons for failures in many other human operations. If accidents occurred every time an engineer passed a red signal there would be an alarming redundancy, for any one with a modicum of experience knows that such occurrence is comparatively common.

The function of train control is to prevent such lapses, such human failures, and remove them from the causes of accident; and, in the inevitable logic of things, that which was originally designed to supplement and to enforce obedience to wayside signal indications will be developed so that the cab signal with automatic braking will in a large measure simplify, or take the place of and remove the necessity for, the wayside signal. No single feature of the Commission's proposed order is more pregnant with meaning than the recognition of this possibility.

EARLY FAILURES.

Reviewing the developments of train stops and train control, it is only fair to the railroads to say that many of the proposals advanced have been but the hasty outcropping of illy-considered and hair-brained projects by inventors whose paucity of knowledge of signal and braking systems and practice, as well as railroad operation, is only equalled by a supreme confidence in their devices as universal cure-alls for railroad ills.

But in these latter years there have been many conscientious and able attempts to solve the admittedly difficult problems of auxiliary train control, to meet the increasing demands of railway transportation, and millions of money have been spent, not always wisely, in furthering projects which gave some promise, and have achieved a measure, of success.

To make the path of progress a little more thorny, various arbitrary requirements have been laid down from time to time as either desirable or essential to automatic train control, some of them confessedly specified in the expectation that success would be made extremely difficult, if not impossible.

The resulting picture was a combination of infallible character which should comprise all the virtue and none of the defects of the ablest operating intelligence of a super-man, signal equipment of undoubtedly chastity and a brake system guiltness of lapses of mechanical morality, regardless of the fact that what is required is not an automaton in the place of an engineman, but an auxil-

iary system of train control which, while fully protecting the train and reënforcing the engineer's intelligence, would leave him practically undisturbed in the handling of his equipment so long as he performed his duties.

WHY GREATER PROGRESS HAS NOT BEEN MADE.

But the fault has not been entirely with the inventors, who have tried, however ineffectually at times, to respond to a pressing

FIG. 4.

Brake application magnet.

need in railroad operation. The responsibility for failure to make greater progress than has attended this development must be laid in considerable measure to the attitude of some of those in position of authority who have successfully discouraged all forward-looking efforts.

Most of those who have been loudest in their expression of disbelief in the possibilities of auxiliary train control simply do not know the facts; and, whether because of technical shortcomings, lack of time, or absence of financial backing, many inventors have been unable to solve the problem. Some of the objectors not only have made no individual contribution to its solution, but they have been inclined to ridicule what has been done constructively by those who have given intensive study to the subject. They have been wont to revel in the difficulties of

railroad operation and to surround it with a cloak of mystery, while assailing the mind with statistics, which, after all, may be most misleading.

THE SOLUTION OF THE PROBLEM.

I am not in entire accord with suggestions frequently made that the development of train control is the province of the operating officers of the various railroads, with their many conflicting ideas and practices as to signal equipment and responsibilities for train operation, but rather, as in the progress of signalling and braking, it is a problem to be developed along catholic lines in such a fashion as to marry together any kind of wayside signal, automatic or manual, or any fundamental method of indicating traffic conditions, with any kind of brake equipment, so as to satisfactorily meet the varying conditions of operation imposed by different train make-ups.

Operating officers must leave experimental work to others who, with ample means, can devote their whole energy and time to new accomplishments, and their attitude should be that of constructive critics. They can, of course, be of the utmost value and usefulness in that rôle, and their active and cordial coöperation is vital to final success.

Freely admitting, as one must, the justice and constructive value of many of the criticisms, even against operative systems, by those in authority, and also the compelling necessity of many of the requisites which have been enumerated, I am of the opinion that there are other possible characteristics which rank of at least equal importance with the majority of them, a fact which the report of the Automatic Train Control Committee of the late National Railroad Administration seems to emphasize in its comments upon speed control, to say nothing of the operative demands which alert critics have imposed upon my own developments.

GENERAL REQUISITES OF TRAIN CONTROL.

We have, therefore, adopted certain basic requisites which seem fundamental for the highest measure of success in meeting the increasingly difficult conditions of the railroad operation.

Specifically, a system should:

Be applicable to any single or multiple track railroad, with or without automatic signal equipment; and in the case of the

former, regardless of whether AC or DC normal danger or normal clear signals are used, with or without interlocks and overlaps.

Be suitable for any road, regardless of the kind of power used, whether steam or electric; and in the latter case uninfluenced by the kind of current or type and location of conductors.

Not encroach upon the clearance lines of rolling stock or

FIG. 5.

Reset track magnet.

track equipment; or be limited by extraneous equipment along the right-of-way; or interfere or be interfered with by snow plows or dragging equipment.

Be unaffected by climatic extremes, proof against interruption by water, snow or sleet, and subject to a minimum of depreciation.

Provide distinctive cab signals and full block protection, as reliably as any possible wayside signal.

Provide speed limitation, regardless of signals, on tangents and curves where required, and insure slowing down to safe running speeds on entering caution territory.

The engine equipment should be:

Readily applied to all types of road engines, passengers

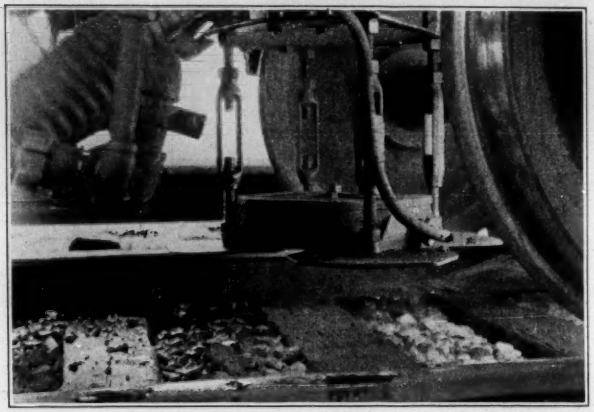
and freight, and once installed be a matter of no concern to the engineman as to adjustment, upkeep or replacement.

Unaffected by shock, jar and vibration, and proof against roadway dust and changes in atmospheric humidity.

Readily replaceable, at least as easily as the standard parts of the regular brake equipment.

Of such character that a locomotive can be used inter-

FIG. 6.



Magnetic receivers in place.

changeably on all kinds of train service, and with any kind of braking which may be required.

Subject to speed control, that is, to a proper coördination of the elements of train speed and braking power of equipment.

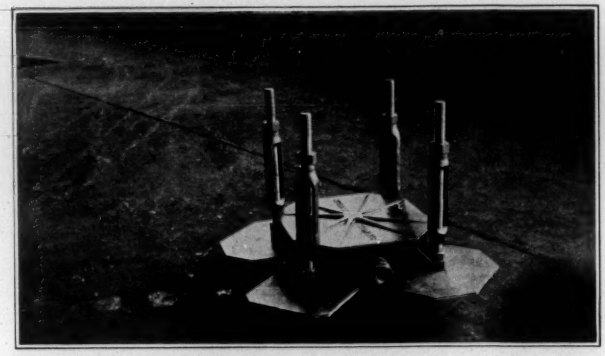
Engine and track equipment should be as nearly as possible fool-proof, and demand the minimum of upkeep and attention, both as to time occupied and special knowledge required; and necessity for adjustments by the engineman should be eliminated.

Finally, the system should be the engineer's friendly mentor and guide, aiding, not unnecessarily opposing, him, a thoroughly reliable but unobtrusive partner in the operation of his engine,

which, while at all times interposing an effective shield between him and disaster, will leave, within all proper limits, the handling of the train subject to his judgment.

I have specified a somewhat complete system, to meet the varying conditions of railroad operation, but any system should be capable of abbreviation where simpler requirements are suffi-

FIG. 7.



Magnetic receivers dismounted.

cient. Yet an analysis of possible equipments will readily show the limitation of choice if satisfactory results in railroad operation are to be obtained.

SPRAGUE SYSTEM.

To illustrate the above system I will give a brief progressive explanation of how this intermittent non-contact system of train control may, by a suitable choice of unit elements, be made to apply to all operation traffic conditions, varying from the simplest automatic stop to complete train control.

GENERAL FEATURES.

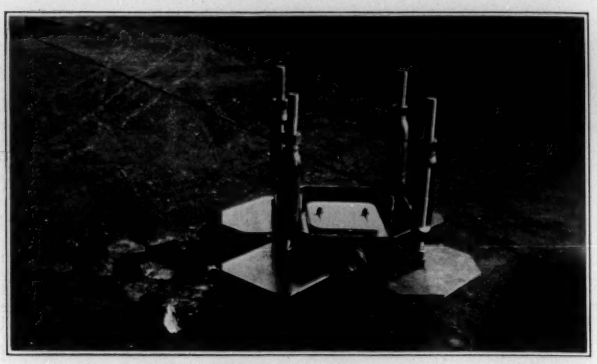
The equipment is divided into two classes:

A. *Trackway elements,* comprising one or more permanent impulse magnets carried on the ties and well below the plane of the rail heads, with means for neutralizing the active field for "clearing," under either manual or automatic con-

trol of traffic conditions, and with either hand or permanent magnet resets, or electromagnet resets controlled by traffic conditions.

All magnets are in the centre line of the track, and the brake application and reset magnets are positioned at right angles to each other, thus insuring universal registration, regardless of direction of movement or heading of locomotive.

FIG. 8.



Magnetic receivers cover off, showing floating receiver.

B. *Locomotive apparatus,* comprising a part or all of the following:

A single or double magnetic impulse receiver,
Relays and pilot valves,
Signal lights and audible alarm,
An interchangeable engineer's brake-head,
Single or duplex service brake valve, with means for automatically limiting reduction of brake pipe pressure,
Emergency valve,
Speed-brake controller,
Differential control valves,
Selector and cut-off valves.

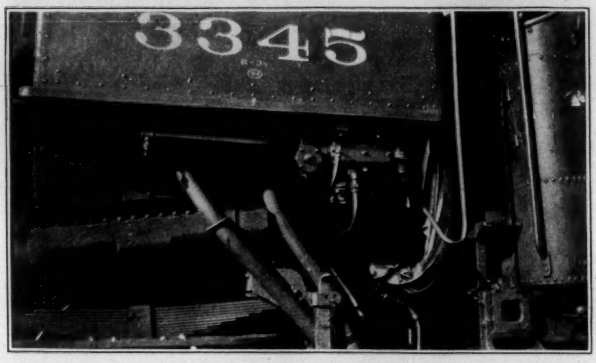
With the above units of apparatus for trackway and loco-

motive it is possible to assemble an equipment which will meet anything from the minimum to the maximum of traffic demands, according to the amount of protection and control required, and with, of course, corresponding variations in initial and maintenance costs.

The flexibility of this selection is indicated by the following typical illustrations:

First: *Track equipment with only one brake application magnet per block and no reset track magnet.*

FIG. 9.



Air valve assembly mounted under cab.

With this equipment there are the following possibilities:

1. *Single-impulse stop.*

In this, the track equipment of but one normally active track magnet per block may be under either manual or automatic control of traffic conditions.

The engine equipment comprises:

Single magnetic receiver,
Interchangeable engineer's brake-head,
Single control relay,
One pilot valve,
Limited service brake valve, with adjustable automatic cut-off, or, as an alternative, an emergency brake valve, the former being preferable, and
Manual reset.

This is the simplest possible equipment. The locomotive receives a single momentary initiation brake impulse when in the block in rear of an occupied block, which impulse is followed at once by a limited service (or emergency) brake application, regardless of speed. After the braking has become effective the relay and pilot valve may be restored to normal position by joint action of the engineer and fireman, and the brakes released manually. After release the train is free to be accelerated.

2. *Single-impulse stop, with low-speed limit provision.*

In this the track equipment is identical with that in No. 1, that is, there is but one brake application magnet per block, under control of traffic conditions, and there is no reset magnet.

The engine equipment is also identical with that in No. 1, except that there is added a flexibly nose-supported gear-driven speed-brake controller, the limits of which may be readily manually adjusted.

With this equipment, if the train speed has been reduced below a pre-determined limit when an active track magnet is reached the brakes will not come on, but they will become effective if the speed has not been so reduced, or is increased above this limit before the engine relay is reset. After such reset by the engine crew the train is free to be accelerated.

3. *Single-impulse stop, with automatically variable low-speed limit.*

In this the track equipment is identical with that in examples Nos. 1 and 2.

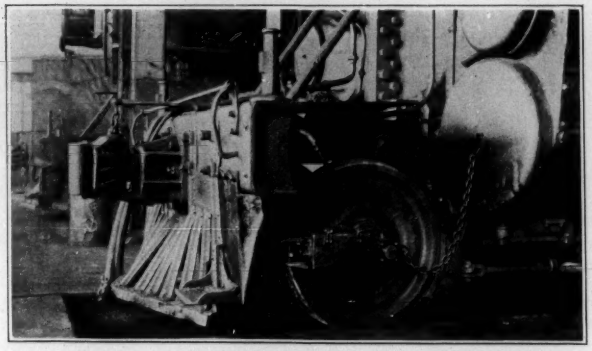
The engine equipment is the same as in No. 2, except that instead of the speed controller having only a manually adjustable low limit to which the train speed must be reduced before passing an active home magnet, it has an automatically adjusted low limit determined by a coördination of two movable parts, one responding to train speed and the other to train brake pressure, so that if the train is being properly braked on passing an active home magnet the automatic will not come on. The minimum speed at which a train may pass the track magnet is also readily adjustable. After the engine relay is manually reset by the engine crew the train may be accelerated at will.

4. *Single-impulse stop, with a two-degree alternative braking and variable speed control.*

In this, also, the track equipment is identical with that in the foregoing examples, Nos. 1, 2 and 3.

The engine equipment is the same as in No. 3, except that there is provided either a double automatic service brake valve, giving light and heavy service brake applications, with limited cut-off, or an automatically limited service valve in combination with an emergency valve.

FIG. 10.



Variable speed-brake controller.

The operation is the same as in No. 3, except that if the speed in passing an active brake magnet exceeds the maximum which is safely controllable with manual service braking equal to the primary automatic braking provided, within the required stopping distance, then the secondary braking, whether increased service or emergency, will come on.

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[2] In the above equipments it will be noted that as there are no track resets the restoring of the engine relays must be by the operation of one or more push buttons, one of which may be located outside the cab, and where two are supplied they require the coöperation of engineer and fireman.

Also, all brake impulses are single, and when once the brakes are applied they are effective to bring the train to a stop; but when the engine relays are reset by hand the train is free to proceed without limit of acceleration so far as the automatic apparatus is concerned.

In examples Nos. 2, 3 and 4, in fact on all equipments, a maximum speed provision may also be readily added, so as to provide speed limits on tangents.

The service brake valve settings are readily adjusted to any required brake-pipe reduction and corresponding brake effort.[2]

Second: *Blocks with one brake application magnet and one reset magnet, either permanent, or electro under control of traffic conditions.*

The track resets, located near the end of each block, that is, following the brake application magnets in sequence of registration, may be either fixed in character or subject to manual or automatic control of traffic conditions.

In the first case the reset simply restores any engine relay which has functioned in passing over an active brake application magnet to its normal condition when the train reaches the end of the block, regardless of traffic conditions, while in the second case the reset is effective or not according as the advance block is clear—thus enabling a train, after receiving a brake application impulse, to be held down to any pre-determined low limit of speed until it has passed over an active reset magnet, so conditioned by a favorable change of traffic conditions.

It follows that the locomotive equipment indicated in examples Nos. 2, 3 and 4 has a reset circuit operated—not by hand as hitherto described but by another track impulse. This, therefore, requires an additional impulse receiver on the locomotive, which may be either separate from the brake impulse receiver or be a composite with it.

In using a fixed track reset the new combinations of the equipment, corresponding in all other respects, except as noted, with examples Nos. 2, 3 and 4, may be designated as follows:

5. *Single-impulse stop, with low-limit speed provision and fixed track reset.*

6. *Single-impulse stop, with variable speed control and fixed track reset.*

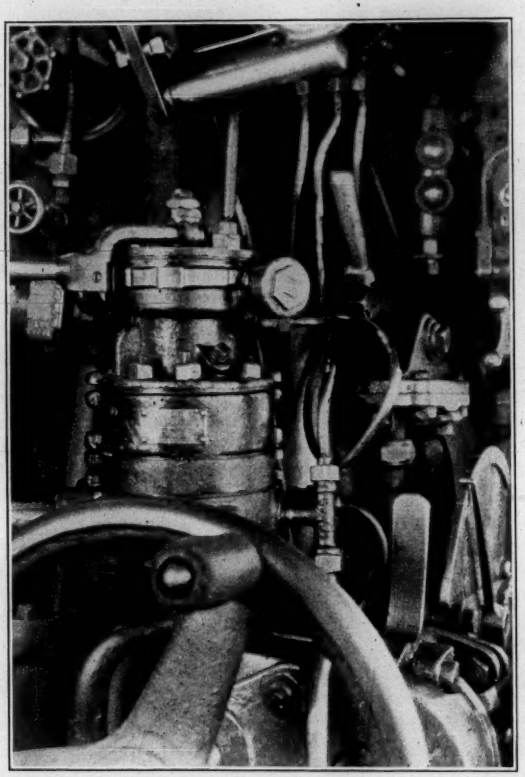
7. *Single-impulse stop, with a two-degree alternative braking, variable speed control and fixed track reset.*

If instead of a permanent track reset one under control of traffic conditions is used, then the locomotive equipments, modified as noted in examples 2, 3 and 4, will give combinations which may be designated as:

8. *Simple-impulse stop, with low-limit speed provision and traffic-controlled reset.*

9. *Single-impulse stop, with variable speed control and traffic-controlled reset.*

FIG. 11.



Main engineer's valve and signal lights in engine cab.

10. *Single-impulse stop, with a two-degree alternative braking, variable speed control and traffic-controlled reset.*

In the equipments thus far described there has been provided but one brake application track magnet per block, without or with

a fixed or a traffic-controlled reset magnet; and only one brake application magnet, that in the rear of an occupied block, is under the control of that block.

It should be pointed out that the brake-application magnets are normally active, and the traffic-controlled resets normally dead, that is, both are installed on a normal danger principle, the clearing current being effective only when a train enters a block immediately in rear of an unoccupied block.

To further extend protection, still using but one application magnet to a block, but with a traffic-controlled reset, the signal circuits may insure that the brake application and reset magnets in the *two* blocks immediately in rear of an occupied block are under the control of that block.

With this arrangement, a train approaching an occupied block may receive two brake-initiating track impulses, one in the block second in rear of the occupied block, that is, while approaching a caution indication, where wayside signals are used, and another in the block immediately in rear of the occupied block.

These impulses may be termed "primary" and "secondary," and will be effective according to the kind of equipment which is supplied on the locomotive.

Where a plurality of alternative results—as will be referred to later—is not provided there will follow, according to the equipment which has been installed, either: A light limited service brake application, succeeded by a possible full service application; or, a heavy service application, followed by a possible emergency application, and the secondary braking will be under a fixed or variable speed control. The train will thus be doubly warned, and finally, if necessary, automatically braked.

With this arrangement of track magnets, if the leading train passes into its next advance block before the following train reaches the reset magnet of its own block, the engine relays of the latter will be restored to normal and only a primary impulse will be received in the following block. This combination, especially with a coördinated variable speed-brake control, is all that many railways will require.

It will be noted that any brake application magnet may be either a "caution" or "home" magnet.

To meet the above conditions the engine equipment is augmented by the addition of another relay, to provide for the proper sequence of brake impulse results and functioning of the reset.

With the above as described we have therefore an equipment which may be designated as follows:

11. *Two-block double-impulse stop, with variable speed control and traffic-controlled reset.*

On congested service, and to provide for interchangeability of locomotives for different train make-ups, a more complete engine equipment is necessary.

With this end in view, the valve assembly of the engine equipment includes one adjustable double-limit service brake application valve with automatic cut-off, and also an emergency valve. To these is added a rotary selector valve, which makes it possible, with only two brake application impulses from the track, to get a variety of results, according to the selector valve used and its setting.

For example, the first brake impulse may give either:

Simply a warning, or
Light service application, or
Full service application,

and the second brake impulse may give either:

Heavy service application, or
Emergency application.

Resulting combinations are evident, as, for example:

Warning and then a limited service application, or
Light service followed by a full service application, or
Full service followed by an emergency application.

There is, however, this limitation—that any brake application received on the first impulse may be immediately released by the engineer before becoming effective if below a pre-determined speed, but the second automatic brake application may be avoided only if the engineer insures the proper braking of his train, either automatically or manually, before reaching an active home magnet, and maintains sufficient braking until his train has been reduced to the permissible low speed for proceeding, a condition of safe procedure indicated by a yellow "proceed" light in his cab.

Violation of this condition, or having brought the train to low control speed, the train speed is increased before reaching an active reset, will cause the secondary brake application to take place. On the other hand, proper handling of the train will keep it completely under the control of the engineer.

In addition, provision is made so that if the brakes have actually come on automatically they may be released either man-

ually from the cab, or only, after an enforced stop, from the ground in coöperation with the engineer.

The equipment thus described may be designated as:

12. *Two-block double-impulse stop, with selective braking, variable speed control and traffic-controlled reset.*

When the train service is highly congested and it is necessary to permit the maximum of train movement with full protection, each block may have two brake application magnets instead of one, which with the reset magnet are all under control of the traffic conditions of the next advance block. Both brake application impulses will, therefore, occur in a single block at shorter intervals. This combination—using the selective braking locomotive equipment specified under No. 12—may be designated as:

13. *One-block double-impulse stop, with variable speed control and traffic-controlled reset.*

The following table shows the general characteristics of these various equipments:

Scheme No.	Brake Magnets per Block.	Brake Impulses.	Resets.	Kind of Braking.	Low-speed Limit.
1	One	One	Manual	Single	None
2	"	"	"	"	Fixed low
3	"	"	"	"	Variable
4	"	"	"	Alternative	"
5	"	"	Fixed track	Single	Fixed
6	"	"	"	"	Variable
7	"	"	"	Alternative	"
8	"	"	Traf. contr.	Single	Fixed
9	"	"	"	"	Variable
10	"	"	"	Alternative	"
11	"	Two	"	Double	"
12	"	"	"	Selective	"
13	Two	"	"	"	"

Groupings.—Nos. 1, 2, 3 and 4. Single brake impulse. One application magnet per block and no track reset.

Nos. 5, 6 and 7. Single brake impulse. One application and one permanent reset magnet per block.

Nos. 8, 9 and 10. Single brake impulse. One application and one electro reset magnet per block.

Nos. 11 and 12. Double brake impulse. One application and one electro reset magnet per block.

No. 13. Double brake impulse. Two applications and one electro reset magnet per block.

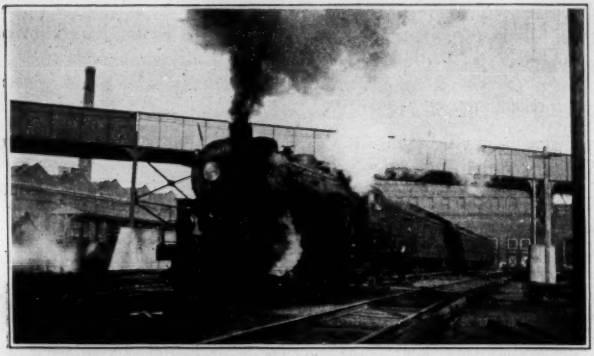
COMPARATIVE ADVANTAGES OF VARIOUS EQUIPMENTS.

Of these various arrangements:

No. 1 is the simplest, but requires either an absolute stop, which would interfere with traffic, or a permissive release, which has certain objections.

Nos. 2, 5 and 8 are not as good as 3, 6 and 9, because these latter provide a *variable* instead of a *fixed* low-speed limit, and hence are more efficient, even if but one brake impulse is used.

FIG. 12.



Test train in yards.

Of 3, 6 and 9, which call for *hand, fixed track* and *traffic-controlled* resets, respectively, the latter, 9, is of course to be preferred.

Again, 7 and 10 are preferable to 6 and 9, because they provide for *two* degrees of braking with a *single* impulse, according to speed; and 10 is, of course, better than 7, because the reset is *traffic-controlled*.

Next, 11 is preferable to any of the preceding arrangements, because it provides for *successive impulses* in *two blocks*, caution and home, and *two degrees* of braking.

No. 12 is even superior, because by use of differential and selector valves each impulse may have either of a pleurality of predetermined results, and the variable combinations of these

are such as to make the same equipment interchangeable for all kinds of traffic. This arrangement is sufficient to meet the operating conditions on a large class of railroads.

No. 13 is an alternative of 12, but only in so far as the track equipment is concerned—there being two brake application magnets in each block, instead of one, as in all the preceding arrangements, as well as a track reset; and both impulses are confined to one block, as may be required in the densest traffic.[3]

REVIEW.

Time does not permit a full description of the equipment above outlined, which has been developed largely under the criticism, and in consequence, of many exacting demands made by the operating officials of a great railroad.

It will be noted that it depends for its track impulse upon that fundamental on which are based every electric light and power plant, every electric railway, every signal system, and every compass, telegraph instrument and telephone—magnetic induction and its power to influence any conducting medium within its scope. If it may be relied upon in so vast a field we can surely use it in this particular one.

The question naturally arises: Why is it that this particular application stands almost unique in the field of automatic train control? It is simply because much had to be learned by long and costly experience as to how to meet the many conditions incident to track and engine equipment, and new practices developed to make use of fleeting impulses of small energy value. But perplexing as these at times have appeared the difficulties have been fully surmounted, with results that are in the highest degree gratifying.

The monetary impulses initiated by the passage of a train through the active fields of the normal danger track magnets, under automatic or manual signal control, having been received on the locomotive, certain static conditions are established, persistent throughout the block, which makes possible, with the same apparatus, to meet the opposing extremes of braking requirements imposed by long tonnage freight and fast passenger trains, regardless of the character of the brake equipment on the trail cars.

[3] No. 13 is the equipment provided in the New York Central tests, but it can be readily abbreviated to illustrate any of the other arrangements.

It will provide, at the will of the management, any required combination of alarm and primary and secondary brakings, the former of measured and limited service character, and the latter, service or emergency under speed-control, and subject to the rules of the road with regard to the making of a positive stop or proceeding under control.

It will afford complete block protection, and also put a restraint not only upon the permissible running speeds in a caution block, but upon excess speeds on tangents and dangerous curves.

It need never apply uncontrolled braking if the engineman obeys his orders and the indications of his cab signals.

The impulse receivers on the locomotive equipment are replaceable as units; sealed when installed, and proof against running shock, vibration, dust and humidity.

The electric relays are likewise sealed, and the connections are made automatically. As a measure of their reliability it may be stated that the number of movements of the contact parts in the full life of a locomotive would not equal those on a "flivver" in a single day.

The speed-brake control mechanism is axle-centred, gear-driven and spring-suspended, as in my fundamental and now universally used railway-motor practice; it is likewise sealed and proof against dust and humidity.

The electric and air valves form a single assembly, much on the order of the distributing valve of the standard brake equipments, and are replaceable as a whole or in parts.

The local electrical supply on the locomotive is from a storage battery, or the headlight generator, or both simultaneously, and the battery is charged by the generator as in automobile practice.

Save for the speed-control, every part of the locomotive equipment is normally in a static condition. None of it is open to the inspection of, or requires adjustment by, the engineer. Replacements would ordinarily be periodic only, the same as obtains with the triple valves.

All parts, air or electric, of the locomotive apparatus may be readily replaced, and when removed may be taken apart and reassembled without any special tools whatever.

The readiness of the equipment for operation is automatically assured when the engine is put into operation, and cutting it out

when the engine is laid up requires the minimum of manual attention, being made a function of the air brake conditions.

It will operate efficiently, regardless of the type of motive power, or the kind of current or conductors used in an electrical system; also on any combination of double-heading, with the equipment of the leading locomotive cut out or disabled, and when running normally headed or with tender first in direction of traffic on steam equipments, or with either end forward on electric equipment, as well as when pushing equipment ahead of the motive power. It will also afford protection in certain cases of disablement of a part of the equipment.

In case of failure of current supply the equipment may be rendered inactive, so that normal control of locomotive and brakes will remain, but such cut-out is self-detecting.

Neither the installation nor the operation of the train control equipment interferes in any way with the power of the engineer to augment to the limit his braking power to stop his train, and all release of brakes is manual.

All apparatus on the locomotive, as well as on the track, is installed on the normal danger plan.

Finally, the total equipment on the locomotive bulks less and is simpler than the lighting and braking equipment individual to a single trail car on a modern passenger train.

THE NEW YORK CENTRAL TESTS.

The development of the system thus outlined has been the result of large expenditures over a period of nine years, half of which is to be credited to war conditions.

Recently the Sprague Company, in coöperation with the Joint Committee on Automatic Train Control, entered into a somewhat unusual contract for an intensive test with the New York Central Railroad, which has long had this system under special study—a special committee having made a unanimous report in favor of a thorough test.

This test is ordinarily being carried on for seven hours a day, six days a week, on a section covering six signal indications on one of the incoming main tracks near New York, where there is a combination of unusual elements and from which all other traffic is temporarily excluded; and where, also, the conditions permit of several hundred recorded operations a week under varying con-

ditions, as many, in fact, as would occur on a considerable division in normal service.

On this section are also operated heavy electric locomotives and multiple unit trains, with direct current from a third rail and traffic rail return. A normal clear AC signal system is used, while the normal danger track magnets are supplied from storage batteries maintained by a trickling charge from the AC power line.

The quite considerable costs of the tests are borne jointly by the Sprague and the railroad companies, the former supplying the engine and track equipment and the latter the engine and the observation and train cars, the necessary train crew, and the labor and material for the wayside circuits and installation.

For some months the operation of this equipment, which started its preliminary runs on February 20, 1922, will be under the supervision, at least, of the representatives of the Bureau of Safety, the American Railway Association and the New York Central Railroad Company, while duplicate written or graphic records available for all will be made of every official test.

Special tuning up of the track will permit of high running speeds when desired. The speeds already made are fully up to the maximum permitted for this section of the track.

Some lantern slides of location and equipment will be shown, to which brief reference may be made as follows:

On the Track.—In each block are situated two normal danger brake application magnets, one near the entrance end and one at the critical point in the block, and near the exit end is a differential reset magnet. In some other cases but one application magnet need be used, and normal engine conditions may be restored by hand.

These various magnets are under the control of the track relays and the signal blades, the application magnets being normally alive and the reset normally dead.

When a train enters a block in rear of a caution or clear block the application magnets are automatically cleared by a neutralizing current supplied to coils enclosing the working poles, thus permitting the magnetically responsive receiver on the locomotive to pass through the space over the magnet poles without being affected.

If the advance block is not clear then the application magnets will remain at normal danger, or active, and the magnetic receiver is subject to their influence; the reset is then inert.

The track magnets are enclosed for protection in substantial manganese steel casings, thoroughly sealed, and supported in the ballast, between pairs of ties, by extension arms resting upon and secured to the ties.

The application and the reset magnets are placed at right angles to each other in the centre of the right-of-way, thus insuring universal registration with the corresponding receivers, regardless of direction of motion or heading of equipment, and the polar faces are between four and five inches below the planes of the tops of the running rails.

On the locomotive there are:

A double receiver, composed of two pairs of flat iron collector plates, attached to the bottom of a non-magnetic box which is hung from the tender by adjustable supports, these plates being from three to four inches above the tops of the rails, making a total clearance of seven to eight inches. The greater the normal clearance provided the less the influence of unavoidable variations.

Within the box, with its locked top, is a floating continuation receiver in which is concentrated on moving armatures of small mass, which maintain normally closed electric circuits, the magnetic flux picked up by the receiver when it passes over an active track magnet. As the tops of the pole pieces are only eight inches in diameter, the time of passage when a locomotive is running at high speed is very short, say from 1/100th to 1/150th of a second, in which time a small magnetic impulse must be picked up and translated into action, while the apparatus which responds to this minute influence must be indifferent to the shocks and jars inseparable from train movement.

The Relays.—The medium to which the impulses are transmitted, and by means of which they are translated into action, comprises an assembly of three coils, operating self-centering pressure contacts, in a definite sequence, and they will readily respond to impulses as short as 1/1000th of a second. Being sealed, automatically connected, and cushioned, they are likewise proof against undue wear due to shock or vibration.

The Valve Assembly.—The impulses picked up by the receiver, and differentiated by the relays, result in influencing the action of two pilot control valves, whose function is simply to establish an opening to atmosphere of one or other of the piston chambers which control the movement of a ported valve, whose operation

may at will effect any required combination of light and heavy measured service and emergency brake application, under speed control, and with or without enforced stop, or with the privilege of proceeding under limited speed until released—varying possibilities necessitated by the widely differing conditions of train make-up and operation met in practice.

The valve assembly thus briefly described is supported under the shelf of the cab, and is equally applicable to any kind of standard brake equipment. Despite its numerous possible functions it has far less parts and is simpler in construction than the UC triple valve commonly used on high-speed train equipment. Its various parts are, in many particulars, of identically the same character as other parts of the air-brake system. They may be separately removed and require only like care and attention.

Speed Control Mechanism.—This is carried on an extension of one of the forward truck axles, on which it is centred on one end, while the other end has a spring-suspended nose support. The drive is by enclosed bevel gearing, running in oil, while the governor part is carried in a dry chamber in which are also supported certain fixed and movable end-contact carbon brushes.

To the free end is carried a flexible cable, terminating in a standard coupling, and also a single flexible air hose connected to the engine brake system. The whole constitutes a combination of a speed-responsive device (not an odometer) and a brake-responsive device, by means of which the necessary coördination may be automatically secured to prevent unnecessary operation of automatically initiated braking.

The above elements constitute the external part of the locomotive equipment, except for the battery and the standard headlight generator, which are the sources of electric supply for the engine equipment, these to be used independently or together.

The remaining parts, which are in the cab, are of the simplest character. One is a manually and power-operated engineer's valve, interchangeable with the standard valve, to which air-oil pressure is delivered when a track impulse is received, to move the handle to lap position, the actual braking other than manual being assured by the automatic valves already referred to.

In addition to this engineer's valve there are two pairs of signal lamps, one on each side of the cab, which show a green light when the equipment is in running order and the block ahead is clear,

and a yellow "proceed" lamp, which indicates the relations existing in the speed-brake control and hence the condition of safe procedure.

COMMENT ON CARRIERS' TESTIMONY.

Some brief comment may be permitted on the testimony presented in Washington on the subjects of cost, depreciation, capacity and interchangeability, and a specific objection which has been raised elsewhere—the possible negative result of train control in the event of an angle cock in the train pipe being closed, the cause of a grave railroad accident a couple of years ago.

With regard to this last objection, the present angle cock is a weak point in all braking systems, and hence there has been developed by associated interests a semi-automatic angle cock which promises, according to many private tests, to eliminate this weakness and make impossible the cutting-off of the power to brake a train, either manually or automatically, after a train pipe has been charged.

Pleadings which emphasize the need of universal interchangeability and completeness of equipment to make automatic train control of practical value may be plausible, but these have been many times advanced with regard to other present-day developments, and are effectually refuted, for example, by the variation in electric railway equipments, and by the fact that many roads are operating the same equipment over lines only partly equipped with automatic wayside signals.

As regards comparative operating capacity, I am satisfied that, considering all the varying conditions of visibility, cab signals with auxiliary brake control will materially increase the safe capacity of roads not now operating under automatic block signals, and where such are in use the capacity will not be restricted. The conditions under which the New York Central tests are being conducted will afford opportunity for a strict comparison in this respect, and with graphic records of performance under both conditions which cannot be disputed.

COSTS.

In the matter of cost and depreciation the opinions expressed are in the main highly fantastic, and totally lacking in that detail which would entitle them to serious consideration. The cost of installation is necessarily variable, according to the amount of

protection required, the extent of existing wayside equipment, the size of the installation and the type of apparatus employed.

This cost is made up of that of three distinct parts:

Engine apparatus,
Track equipment,
Wayside installation.

The first two items may of course be definitely given, but they may only be fairly considered in connection with the question of depreciation, for the saving of even a hundred dollars a mile in the latter item corresponds, on an eight per cent. basis, to a capital equivalent of twelve hundred and fifty dollars.

It has been stated that, considering the total costs, the interest charge, depreciation and up-keep would amount to as much as a thousand dollars per annum for each mile of track equipped. The absurdity of such a statement should be apparent to anyone, and can only be excused on the ground of complete ignorance as to what has been accomplished, for after allowing liberal charges on the cost of equipment and installation there would still remain over eight hundred dollars per mile for upkeep, or the capital equivalent of ten thousand dollars per mile.

Reduction in depreciation is, therefore, of far greater moment than undue scrimping in first costs. Special effort has been directed to this matter, with such gratifying results that I know this item can be maintained well within moderate limits.

COMPARISON OF DEPRECIATION.

As an illustration of the difference, for example, between a third-rail contact device and one actuated by magnetic induction, I may cite certain approximate comparative ratios as follows:

Necessary number of movements of contacts	1 to 200
Train movement required for operation	1 to 100
Contact movement	1 to 200
Pressure on contact	1 to 5000
Rubbing contact:	
None on one, and	
Serious on the other.	
Impact:	
None on one,	
Large on the other.	
Exposure:	
One completely enclosed,	
The other always exposed.	

In short, the depreciation of the receiver parts in the induction system is represented by a practically irreducible minimum.

A similarly low depreciation must exist with regard to sundry parts of the engine equipment, such as the relays, and to a less degree the speed-control mechanism; and as to the other parts they are of the order common to standard air-brake equipment.

The costs of wayside equipment depend upon many factors, such as the existence, or otherwise, of poles and common circuits, whether the poles are owned or leased, whether a DC or an AC signal system, or none, is used, and the kind or capacity of batteries in the former, the presence or absence of AC power lines, and so on.

The requirements as to wayside pole circuits, with the usual common return and clearing lines, are the equivalent of one conductor per signal indication, roughly per mile of double track, and the fundamentals of our track magnet circuits are elemental in character. Their application to existing circuits is a matter of ready adaptation by signal engineers, and one affording no excuse for complication or material expense.

The power used in the circuits of the track magnets for clearing them, when installed on the normal danger system, is inappreciable, for, except in a special case, current is used only when a train is passing through a block and the advance block is clear. It is a function of the number of locomotives in use, regardless of the length of the division, and according to present experience would average a kilowatt rate for from fifty to seventy-five locomotives in service, divided among all the batteries on the line—less than is required to light a single passenger car.

While the system described has been developed under my direction it would be a mistake to assume that it is the product of any single mind, for it represents an accumulation of invention and experimental work in which my various associates have played a large part, notably our Chief Engineer, Lt. F. D. Sprague. I might add that we are also deeply indebted to the criticisms and suggestions of signal and brake experts, the natural result of many intimate contacts with them.

Elementary Proof of the Form of the Caustic by Reflexion. G. CESÀRO. (*Bulletin, Section of Sciences*, Royal Academy of Belgium, No. 7, 1921.)—The caustic, "the cow's foot in the milk," is that cusped bright line found somewhat in front of a mirror of cir-

cular, not parabolic cross-section, when a beam of sunlight, parallel to a radius, is incident upon the reflecting surface. Two adjacent rays of the beam give rise to two reflected rays, which intersect at some point that is unusually bright because it gets energy from more than one ray. Let a beam of sunlight travel along the axis of a cylindrical napkin ring or of a tumbler, then tilt the object a little and the caustic becomes visible on the bottom of the tumbler or on a piece of paper across the end of the ring.

The form of the caustic has long been known, but for its derivation and investigation the differential calculus has been employed. Now Cesàro furnishes a derivation with nothing but algebra, geometry and elementary trigonometry, and all so simply explained that a good high school graduate can follow him. Would that the author might turn his talents to the elucidation of the Theory of Relativity!

With consummate art, for the article is "of a lucidity," as the French would say, we are led by easy steps to recognize that the caustic is an epicycloid. About the centre of the reflecting surface describe a circle with half the radius of the surface. Upon the radius of the reflecting surface, parallel to the beam of light and between this surface and the smaller circle just drawn, put a circle with a radius of one-quarter of the radius of the surface. This smallest circle is tangent to the surface and to the circle just drawn. This just mentioned point of tangency is a point of the caustic and is at the cusp. Now roll the little circle upon the inner circle. The point of the moving circle which was at first in contact with the inner circle describes the epicycloidal caustic as it moves away from its former contact, whether up or down.

G. F. S.

Isopropyl Alcohol.—The manufacture, properties, pharmacology, and uses of isopropyl alcohol are described by DUDLEY H. GRANT and CARL O. JOHNS (*Am. J. Pharmacy*, 1922, x-c iv, 418–425). This alcohol is a by-product of the petroleum and natural gas industry. The olefine gases, including propylene, are absorbed in sulphuric acid; and the resulting alkyl sulphuric acids are hydrolyzed with the production of alcohols. Propylene yields isopropyl sulphuric acid; and this compound is converted into isopropyl alcohol by hydrolysis. Isopropyl alcohol is readily dehydrated by a short digestion with an excess of dry sodium hydroxide, and subsequent distillation. It is more toxic than ethyl alcohol, but far less toxic than methyl alcohol. Isopropyl alcohol may be used as a dehydrating agent, an antiseptic, an antidote for phenol burns, a sterilizing medium for ligatures and instruments, a preservative for anatomical and pathological specimens, a key denaturant for industrial alcohol, a solvent in the manufacture of five chemicals, synthetic drugs, plant principles and related substances, a precipitant, and for other purposes.

J. S. H.

THE STABILITY OF ATOM NUCLEI, THE SEPARATION OF ISOTOPES, AND THE WHOLE NUMBER RULE.*

BY

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INTRODUCTION.

SINCE almost all of the books and most of the papers which have been published during the last decade on the subject of atomic structure are the work of physicists, it is but natural that the chemical facts which are of fundamental importance in connection with such a subject have been largely ignored, except in such portions of the field as have been popularized by certain chemists. During the last few years these chemists have succeeded in replacing the physicist's theory that the atom lies in a plane, by the more useful idea of Parson, G. N. Lewis, and other chemists, that it is three dimensional. These theories refer to the structure of the outer part of the atom.

Chemical facts are of prime importance also in connection with the study of the structure and stability of the innermost core, or nucleus of the atom. However, the chemical facts are so numerous and so detailed that it is difficult for physicists to comprehend them without a careful study, so they are usually disregarded, even so much so that in some cases experimental results have been published which were seemingly not in harmony with the general system revealed by such facts. In such cases later work has shown the original experimental results to be erroneous.

The chemical data which are of the most value in the study of the stability of the nuclei of atoms are the accurately determined chemical or mean atomic weights. Since it has been discovered that most elements are mixtures, and that therefore the chemically determined atomic weights are usually only mean values, there has been a tendency to minimize the importance from a scientific viewpoint, of the determination of such values. It is the purpose of the present paper to show, so far as is possible in its limited

* Presented at the Stated Meeting of the Institute, held Wednesday, April 19, 1922.

scope, that the discovery of isotopes has made the mean atomic weights assume a place of much greater importance, since they now become the fundamental basis for studies of nuclear composition and stability. That this is true is of interest to chemical science in America, since it is in this country that the most important work on atomic weights has been carried out by T. W. Richards, and by his coworker, G. P. Baxter.

1. INTERPRETATION OF THE ATOMIC WEIGHTS.

Early in the year 1914 the writer had occasion to make a detailed study of the atomic weights of the eighty-six elements then known, and it was evident at that time that they revealed a very remarkable story: That of the building of the atoms. This took the form of several papers,[1] published in 1915, which revived the hypothesis, published just a century before by Prout,[2] that hydrogen is the fundamental substance or protyle from which all other substances are built. When first presented Prout's idea received the vigorous support of Thomson, considered in England as one of the leading chemical authorities of the day. Many years later, from 1840 to 1860, it was advocated by Dumas, who made a large number of atomic weight determinations during this period. For a time, during the first half of the eighteenth century, many other chemists, among them Gmelin, Erdmann, and Marchand, were also numbered among Prout's supporters. On the other hand, the most accurate of workers on atomic weights, Stas, who in the beginning tried to aid Dumas in the revival of Prout's hypothesis, afterward designated it as pure fiction, since he was fully convinced of this by his own extremely accurate atomic weight determinations, and Berzelius at all times adhered to the view that exact atomic weights could not be determined except by experiment.

The basis of Prout's idea was the fact that he found the atomic weights of a considerable number of elements to be whole numbers as shown in Table I.

Since, as is obvious from the table, most of the atomic weights used by Prout are very far from being correct, it is apparent that the evidence for his hypothesis was very faulty. Indeed the fact that the chemical atomic weights are on the whole

[1] *Proc. Nat. Acad. Sciences*, 1, 276 (Feb., 1915); *J. Am. Chem. Soc.*, 37, 1367–1421 (June, 1915); *Phil. Mag.*, 30, 723–34 (1915), Harkins and Wilson.

[2] *Annals of Philosophy*, 1815.

far from whole numbers when hydrogen is taken as a basis, led to the rise of a strong prejudice against this idea, as is well illustrated by a quotation taken from the 1906 edition of Meyer's history of chemistry.

TABLE I.

Prout's Table of the More Accurately Determined Atomic Weights.

Element.	Sp. gr.	Atomic weight, 2 vols of hydrogen being. 1.	Present atomic weight.
H	1	1	1.0078
C	6	6	12.00
N	14	14	14.008
P	14	14	31.04
O	16	8	16.00
S	16	16	32.07
Ca	20	20	40.07
Na	24	24	23.00
Fe	28	28	55.84
Zn	32	32	65.37
Cl	36	36	35.46
K	40	40	39.10
Ba	70	70	137.37
I	124	124	126.92

During the period in which Davy and Gray-Lussac were carrying on their brilliant work, and before the star of Berzelius had attained to its full lustre, a literary chemical event occurred which made a profound impression upon nearly all the chemists of that day, *viz.*, the advancement of Prout's hypothesis. This was one of the factors which materially depreciated the atomic doctrine in the eyes of many eminent investigators. On account of its influence upon the further development of the atomic theory this hypothesis must be discussed here, although it but seldom happens that an idea from which important theoretical conceptions sprang, originated in so faulty a manner as it did.

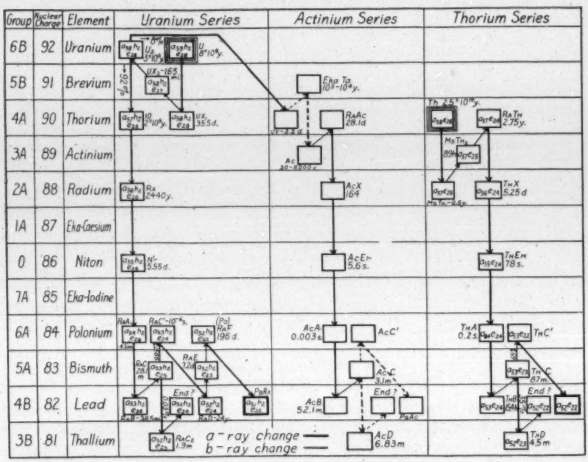
2. THE WHOLE NUMBER RULE: HYDROGEN THE ONLY TRUE ELEMENT.

That the atomic weights are not at all whole numbers when the atomic weight of hydrogen is taken as unity, is shown very plainly in column 2 of Table II. *Thus Prout's hypothesis in its numerical form is not at all true.*

However, the data presented in columns 5 and 6 of the table indicate that the atomic weights of the first twenty-seven elements, with the omission of hydrogen, are, with very few exceptions, very close to the whole numbers, if oxygen as 16 is taken as the basis for the atomic weights. These facts led Harkins and Wilson in 1915 to the first statement of the *Whole Number Rule.* This may be expressed as follows: First, *The atomic weight of any pure*

atomic species is very close to a whole number on the basis of 16 as the atomic weight of oxygen (or of 12 as the atomic weight of carbon, etc.). Second, *The atomic weight may be expected to be even closer to a whole number when it is divisible by 4 than when*

FIG. 1.



it is not so divisible. The simplest explanation of the first and more fundamental part of this rule is that *all atoms other than hydrogen are intra-atomic compounds of hydrogen.* On this basis the whole number rule may be restated in a very simple form. The atomic weight of free hydrogen itself is 1.0078, but the average atomic weight of hydrogen which is combined in any other atom is in general equal to 1.000 ($\pm$ 0.001).

Thus hydrogen itself, or hydrogen in any of its loose combinations known as molecular compounds, has an atomic weight equal to 1.0078, but in general when it enters into the extremely stable combination with itself found in any complex atom, it loses mass to the extent of $\frac{7.7}{0.01}$ per cent. Thus this loss of mass may be considered as the expense of the combination and may be indicated technically as the "packing effect." The origin of this

packing effect will be discussed later in the section on "Mutual Electromagnetic Mass."

The second part of the rule, that the atomic weights are probably closer to whole numbers when they are divisible by 4, is a condition which may need to be imposed upon the first fundamental clause. According to the writer's theory atoms whose atomic weights are divisible by 4 have nuclei which are in general built up wholly from alpha particles which are known to be the nuclei of helium atoms. Now if the aggregation of these alpha particles does not materially influence the packing effect, it is a necessary result, provided there is no appreciable packing effect between the alpha particles, that the atomic weights of all such atoms should be divisible by the atomic weight of the helium atom, which would be one-fourth of the atomic weight of the oxygen atom, or exactly 4. On this basis all of the atoms of this class would have whole numbers for their atomic weights. Any hydrogen atoms which are not bound into helium atoms might exhibit some other value of the packing effect. If we assume that the lithium atom consists of one helium atom and three hydrogen atoms, and that the latter retain the masses they possess when free, then the atomic weight of this isotope of lithium would be 7.023 and on a similar basis the atomic weight of nitrogen would be 14.016. The experimentally determined atomic weight of nitrogen is 14.008, and it is a problem of prime importance to determine if the 0.008 is due to error, to the presence of a heavier isotope, or to a smaller packing effect than exists in atoms which are aggregates of helium atoms alone.

The general theory indicates that even for those atoms which are intra-atomic compounds alone, the whole number rule cannot be expected to be entirely exact. The possible deviations will be discussed in connection with a consideration of the energy emitted during the disintegration of radioactive atoms.

While the validity of the whole number rule as thus developed in 1915 is now universally recognized, it may be of historical interest to present a part of the discussion on this subject as published at that time, since it will help to show in what way the chemical atomic weights were interpreted.

In discussing the deviation of the atomic weights on the basis of hydrogen as 1, from a whole number, Harkins and Wilson stated:

TABLE II.

Deviations of the Atomic Weights from Whole Numbers.

	At. wt. H = 1.	Diff. from whole number.	Per cent. variation or the packing effect.	Possible per cent. variation.	At. wt. O = 16.	Diff. from whole number.	Per cent. variation from whole no.	Prob. error in at. wts.
H*....	1.000	....	....	....	1.0078	+0.0078	0.78	0.0002
He†...	3.97	−0.03	−0.77	12.5	4.00	0.00	0.00	0.01
Li.....	6.89	−0.11	−1.62	7.1	6.94	−0.06	−0.86	0.01
Be....	8.93	(+0.03)	....	5.5	9.0	+0.0	0.00	0.05
B.....	10.91	−0.09	−0.77	4.5	11.0	0.00	0.00	0.05
C‡....	11.91	−0.09	−0.77	4.2	12.00	0.00	0.00	0.005
N.....	13.90	−0.10	−0.70	3.6	14.01	+0.01	+0.07	0.005
O.....	15.88	−0.12	−0.77	3.1	16.00	0.00	0.00	0.00
F.....	18.85	−0.15	−0.77	2.6	19.00	0.0	0.0	0.05
Ne‡...	19.85	....	....	....	20.0	....	....	....
Na§...	22.82	−0.18	−0.77	2.2	23.00	0.00	0.00	0.01
Mg....	24.13	+0.13	+0.55	2.15	24.32	+0.32	+1.33	0.03
Al....	26.89	−0.11	−0.77	1.85	27.0	0.00	0.00	0.0
Si.....	28.08	+0.08	+0.31	1.78	28.1	+0.10	+1.07	0.1
P.....	30.78	−0.22	−0.71	1.61	31.04	+0.04	+0.12	0.01
S‡....	31.82	−0.18	−0.56	1.56	32.07	+0.07	+0.22	0.01
Cl....	35.19	+0.19	+0.54	1.43	35.46	+0.46	+1.31	0.01
Ar....	39.57	−0.43	−1.07	1.25	39.88	−0.12	−0.30	0.02
K.....	38.80	−0.20	−0.52	1.28	39.10	+0.10	+0.25	0.01
Ca....	39.76	−0.24	−0.60	1.25	40.07	+0.07	+0.17	0.03
Sc....	44.76	−0.24	−0.55	1.14	45.1	+0.10	+0.23	0.2
Ti....	47.73	−0.27	−0.57	1.04	48.1	+0.10	+0.21	0.1
V.....	50.61	−0.39	−0.77	0.98	51.0	0.0	0.0	0.1
Cr....	51.60	−0.40	−0.77	0.96	52.0	0.0	0.0	0.05
Mn...	54.50	−0.50	−0.90	0.90	54.93	−0.07	−0.13	0.05
Fe....	55.41	−0.59	−1.06	0.89	55.84	−0.16	−0.29	0.03
Co....	58.51	−0.49	−0.83	0.85	58.97	−0.03	−0.05	0.02

Per cent. variation of 21 elements (omitting Be, Mg, Si, Cl), or the packing effect ..... = 0.77 %

Average deviation of the atomic weights, H = 1, from whole numbers = 0.21

Theoretical deviation of atomic weights from whole numbers on the basis that the deviations are entirely accidental ..... = 0.25

Average deviation of the atomic weights, H = 1, for the eight elements from helium to fluorine ..... = 0.095

Average deviation of the atomic weights, O = 16, when Mg, Si and Cl are omitted ..... = 0.05

Average deviation of the atomic weights, O = 16, for the eight elements from helium to fluorine ..... = 0.009

*W. A. Noyes ("A Text-book of Chemistry," p. 72) states that the atomic weight used for hydrogen, 1.0078, is probably not in error by so much as 1 part in 5000.

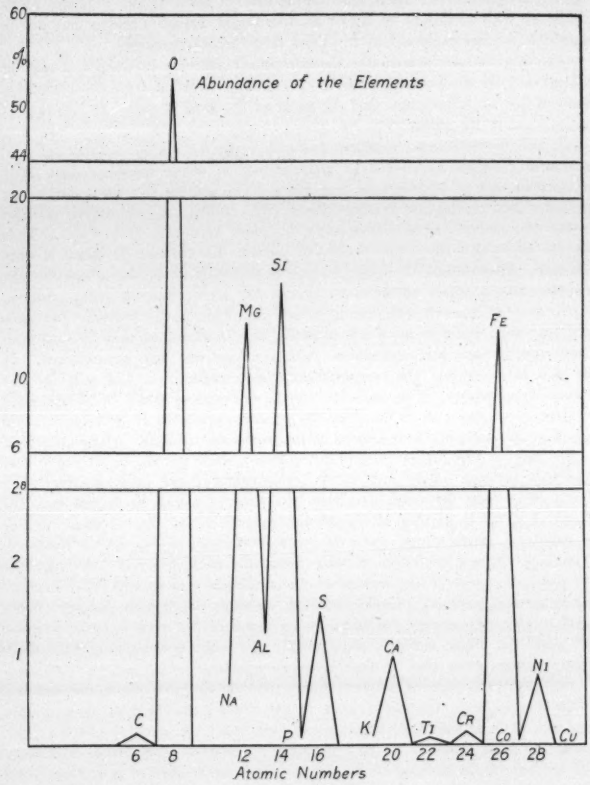
†Heuse (*Verh. duet. physik. Ges.*, **15**, 518 (1913)) obtained the value 4.002 as the result of 7 experiments.

‡Leduc (*Compt. rend.*, **158**, 864 (1914)) gives the atomic weight of neon as 20.15 when hydrogen is taken as 1.0075. Leduc's value is not used, on account of the discovery of the complexity of neon as described in the text of the paper.

§Richards and Hoover (J. Am. Chem. Soc. **37**, 95 (1915)) determined the atomic weights of carbon as 12.005 and of sodium as 22.995, and in Vol. 37, p. 108, they give the atomic weight 06.of sulphur as 32.

Not only is the variation from a whole number a negative number, but in addition its numerical value is nearly constant, the average value for the twenty-one elements being 0.77 per cent., while the six elements from boron

FIG. 2.



to sodium show values of 0.77, 0.77, 0.70, 0.77, 0.77, and 0.77 per cent. The deviation is therefore not a periodic, *but a constant one*. If, then, a modification of Prout's hypothesis that the elements are built up of hydrogen atoms as units is to be taken as a working basis, it becomes important to find a cause for the decrease in weight which would result from the formation of a complex

atom from a number of hydrogen atoms. The regularity in the effect suggests that, in general, this decrease in weight is probably due to some common cause, though the exceptional cases of magnesium, silicon, and chlorine, show that there is certainly some other complicating factor. The discovery of the reason for the deviation of the same kind in the case of neon, where it is due to its admixture with an isotope of higher atomic weight, suggests that it may not be impossible to find explanations for these three other exceptions.

In order to have a term for the percentage decrease in weight, it may be well to call this the packing effect, or percentage variation from the commonly assumed law of summation, that the mass of the atom is equal to the sum of the masses of its parts.

It has formerly seemed difficult to explain why the atomic weights referred to that of oxygen as 16 are so much closer to whole numbers than those referred to that of hydrogen as one, but the explanation is a very simple one when the facts of the case are considered. *The closeness of the atomic weights on the oxygen basis to whole numbers, is indeed extremely remarkable.* Thus for the eight elements from helium to sodium the average deviation is only 0.02 unit, which is less than the average probable error in the atomic weight determinations. When twenty-one elements are taken from the table, omitting the exceptional cases of magnesium, silicon, and chlorine, the deviation averages only 0.05 unit, while if these are included, this is increased only to 0.09 unit. These results have been calculated without taking the sign into account. If the sign is considered the average deviation is reduced to 0.01 unit for the twenty-one elements. The probability that such values could be obtained by accident, is so slight as to be unworthy of consideration. If an oxygen atom is a structure built up from sixteen hydrogen atoms, then the weight according to the law of summation should be sixteen times 1.0078, or 16.125. The difference between 16.125 and 16.00 is the value of the packing effect, and if this effect were the same for all of the elements, except hydrogen, then the choice of a whole number at the atomic weight of any one of them, would, of necessity, cause all of the other atomic weights to be whole numbers. Though this is not quite true, it is seen that the packing effect for oxygen is 0.77 per cent., which is the average of the packing effects for the other twenty-one elements considered. Therefore, those elements which have packing effects equal to that of oxygen will have whole numbers for their atomic weights, and since the other elements show nearly the same percentage effect, their atomic weights must also lie close to whole numbers.

Earlier in the paper it has been shown that the fact that the atomic weights on the oxygen basis are much closer to the whole numbers than those on the hydrogen basis, is explained by what has been called the packing effect, or the change of mass involved in the formation of heavier atoms from hydrogen. The average of the packing effects for the elements considered is 0.77 per cent. This is also the value of this effect for oxygen, which happens to have been chosen as the fundamental element in the determination of atomic weights. If the number representing atomic weight of hydrogen, 1.0078, is decreased by this percentage amount, it becomes 1.0000, *which is the fundamental unit in atomic weight determinations.* The atomic weights of the twenty-five fundamental elements listed in Table II are found, on the whole, to be very nearly

products of this unit by a whole number. While the numerical unit of measurement does not change, the actual unit of mass, the mass of the hydrogen nucleus varies slightly from atom to atom, and this variation may cause a slight deviation of the atomic weights from whole numbers.

The opposite of the system here proposed would be, to suppose that the values of the atomic weights are wholly the result of accident. On this basis the probability that the atomic weights fall as close to whole numbers as they do, may be calculated. In such calculations oxygen is omitted, since its atomic weight is fixed as a whole number, and hydrogen is not used, since its atom contains only one hydrogen nucleus.

The first calculation made was that of the probability that *each* of the atomic weights should be as close as it is to a whole number. The data used are those of Table II. The chance that the atomic weight of nitrogen should entirely, by accident, deviate from a whole number by only 0.01 of a unit was determined by dividing the unit into the 200 divisions corresponding to the assumed accuracy (Landolt-Börnstein-Meyerhoffer, Tabellen) of 0.005. The greatest possible deviation would then be 100 divisions, while the actual deviation of 0.01 unit corresponds to two divisions. The probability is then one-fiftieth. The chance that any number of independent events should all happen is the product if the separate probabilities of their each happening. The probability calculated in this way is 2×10^{-23}, or

$$\frac{2}{10{,}000 \text{ billion billion}},$$

which indicates that there is practically no chance that the atomic weights are entirely the result of accident.

Another probability, which seems to be of more value in connection with the present problem, is that the *sum* of the deviations shall not exceed the sum actually found. This is of the form known as De Moivre's problem, and the method was used by Laplace[3] in calculating the probability that the sum of the inclinations of the orbits of the ten planets to the ecliptic is not greater than the value found at that time, 0.914187 of a right angle. The result obtained was 1.1×10^{-7}. The problem is stated in the following way: An urn contains $n+1$ balls marked, respectively, $0, 1, 2, 3, \ldots n$; a ball is drawn and replaced: required the probability that after i drawings the sum of the numbers drawn will be s. This probability is the coefficient of x^s in the expansion of

$$\frac{1}{(n+1)^i}(1-x^{n+1})^i(1-x)^{-i},$$

or the probability P is

$$P = \frac{1}{(n+1)^i}\left\{\frac{\lfloor i+s-1}{\lfloor i-1 \;\lfloor s} - \frac{i}{1}\frac{\lfloor i-1+s-n-1}{\lfloor i-1 \;\lfloor s-n-1} + \right.$$

$$\left. \frac{i(i-1)}{1.2}\frac{\lfloor i-1+s-2n-2}{\lfloor i-1 \;\lfloor s-2n-2} \cdots\right\}.$$

In the case of the atomic weights P gives the probability that the sum

[3] Laplace: "Oeuvres VII, Theorie Analytique des Probabilites," pp. 257–62.

of the deviations from whole numbers shall equal s, which is not what is desired. The result wanted is the probability that the sum of the errors shall be equal to or less than s, or the summation of the P_s from 0 to s. Now

$$\sum_{s=0}^{s=s} \frac{\lfloor i+s-1}{\lfloor i-1 \; \lfloor s} = \frac{\lfloor i+s}{\lfloor i \; \lfloor s}.$$

So the desired probability, P' is:

$$P' = \sum_{s=0}^{s=s} P = \frac{1}{(n+1)^i} \left\{ \frac{\lfloor i+s}{\lfloor i \; \lfloor s} - \frac{i}{1} \frac{\lfloor i+s-n-1}{\lfloor i \; \lfloor s-n-1} + \right.$$

$$\left. \frac{i(i-1)}{1.2} \frac{\lfloor i+s-2n-2}{\lfloor e \; \lfloor s-2n-2} - \frac{i(i-1)(i-2)}{1.2.3} \frac{\lfloor i+s-3n-3}{\lfloor i \; \lfloor s-2n-3} \cdots \right\}.$$

In solving this problem all of the first twenty-seven elements have been used with the exception of hydrogen and oxygen, and these *should* be omitted for the reasons given above. The errors in the determined values have been taken as they are given in Table II. The atomic weights used in the calculation are as follows:

He..... 4.002	Mg 24.32	Ca.....40.07
Li 6.94	Al 27.1	Sc 44.1
Be 9.1	Si 28.3	Ti 48.1
B 11.0	P 31.02	V 51.0
C 12.005	S 32.06	Cr.....52.0
N 14.01	Cl 35.46	Mn.....54.93
F 19.00	A 39.88	Fe.....55.84
Ne.....20.15	K 39.10	Co 58.97
Na 22.995		

The average probable error as determined from Table I is 0.043 unit, which is equivalent to about twenty-four divisions for one unit, or twelve divisions for half a unit, which is the maximum possible deviation from a whole number. Since n is 12, $n+1$ is taken as 13. The sum of the deviations from whole numbers is 2.342, which is equal to fifty-six of the divisions determined above, or $s = 56$. The number of elements, i, is 26. The probability calculated on this basis is 6.56×10^{-8}, or approximately

$$\frac{1}{15{,}000{,}000}.$$ *

It has been assumed in this paper that the cause of the deviations of neon, magnesium, silicon, and chlorine, which are exceptional in giving positive deviations from the atomic weights on the hydrogen basis, must be different

*Since this was calculated the atomic weights have been changed by new determinations so that they are closer to whole numbers by the following amounts: Be, 0.07 unit; Al, 0.07 unit; Si, 0.2 unit. Thus this probability is now far smaller than

$$\frac{1}{15{,}000{,}000}.$$

from that which gives the deviations of the other elements. The cause of the deviation of neon has been explained, but for the others it is unknown. In the calculations of the probabilities given above these elements have been included. It may be of interest to note that if these elements had been excluded the probability for the twenty-one remaining elements would have been found to be about

$$\frac{1}{7 \text{ billion}}.$$

It is an interesting coincidence that the probability above found for the twenty-seven lighter elements is about 1×10^{-7}, while the probability determined by Laplace that the sum of the inclinations of the ten planets then known, to the ecliptic, should not be greater than the sum of the measured values, is almost the same, or 1.123×10^{-7}. In the second paper of this series it will be shown that the atomic weights not only approximate whole numbers, but that these whole numbers are in addition *certain* numbers which are determined by a special system, and which may be given accurately by an equation of the form

$$W = 2(n + n') + \tfrac{1}{2} + [(-1)^{n-1} \times \tfrac{1}{2}].$$

The probability that the atomic weights should come so close to these *special* whole numbers is much less than that calculated above, so that the words of Laplace may be applied to the system presented here, as well as to the one he himself gives. *That the atoms are built up of units of weight very close to one,* and that therefore this modified form of Prout's hypothesis holds, "est indiquee avec une probabilite bien superieure a celle du plus grand nombre des faits historiques sur lesquels on ne se permet aucun doute."

The accepted atomic weights on the oxygen basis as now used are closer to whole numbers than those given by Ostwald in 1890.[4] Ostwald's numbers are all larger than the corresponding whole numbers, so the deviations were all positive. On the other hand, the present values show both positive and negative deviations. The fact that the small change of 0.77 per cent. from the oxygen to the hydrogen basis eliminates practically all of the tendency of the atomic weights to be near whole numbers, when as many as twenty-seven elements are considered as in Table II, shows that the atomic weight of oxygen cannot be taken as very different from 16.00 without obscuring this relationship. Thus it has been shown that the probability that the atomic weights on the oxygen basis would come entirely by accident as close to whole numbers as they do, is 6.56×10^{-8}, or about

$$\frac{1}{15{,}000{,}000}.$$

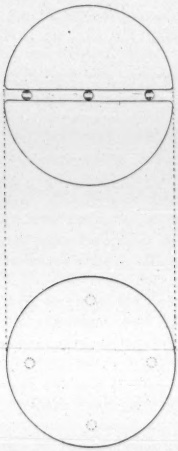
A change of only 0.77 per cent. from the oxygen basis causes an enormous increase in the probability that the atomic weights obtained in this way could be as close to whole numbers as they are, entirely by accident. Thus the chance that the sum of the deviations should come out as equal to, or less than, the sum actually found, is 0.105, or

$$\frac{1}{10}.$$

[4] *Allgemeine Chemie,* I, p. 126 (1890).

As has been seen, there are twenty-seven atomic weights distributed over fifty-nine units of atomic weight. The greatest common divisor of the whole numbers corresponding to the atomic weights is one. *The atomic weights are therefore such that numerically they seem to be built up from a unit of a mass of one, and the probability results seem to show that this unit of mass must be very close to 1.000, expressed to three decimal places.*

FIG. 3.



Model of the alpha particle or nucleus of the helium atom.
The two large deformed spheres represent negative, and the four small spheres positive, electrons.

3. THE NEGATIVE ELECTRON AND THE POSITIVE ELECTRON.

The phenomena concerned with the displacement of negative electrons (negative charges of electricity) are so universal that they have been recognized for thousands of years. Thus a silk cloth rubs off negative electrons from a glass rod, while when fur and a piece of sulphur or rubber are rubbed together these electrons pass from the fur to the other object. Negative electrons escape in considerable numbers from hot wires, they are supposed to be the carriers of electricity in wires, and are driven out of various materials by the action of radiation.

Negative electrons were first discovered in the electrical charges in vacuum tubes. As early as the year 1859, Pflücker showed that the rays produced in such tubes may be deflected by a magnet, and about ten years later Hittorf found that they travel in a

straight line and will not follow a bend in the tube. Varley first considered these rays to consist of electrified matter from the cathode, while Crookes believed them to be a fourth state of matter. In 1895 Perrin proved directly that they carry negative electricity, and the discovery of the electron as a particle or corpuscle was made two years later by J. J. Thomson and by Wiechert.

The charge carried by the negative electron has been found to be 4.77×10^{-10} electrostatic units, while its mass is 1835 times less than that of the lightest atom, that of hydrogen.

Nearly 100 years ago Faraday showed by what is known as the ice-pail experiment that, when electricity is produced, the positive and negative electricity are equal in magnitude, and appear simultaneously. While the smallest mass associated with the negative electron is much smaller than that of the hydrogen atom, the smallest positively charged particle has been found to have practically the mass of the hydrogen atom (1.66×10^{-24} grams). Instead of giving the mass of the hydrogen atom in grams it is customary to designate it as 1.0078. If it is assumed that the hydrogen atom consists of a positive ion and a negative electron, the mass of the former would be 1.0023, while that of the latter would be 0.0055.

Since the hydrogen ion mentioned in the previous paragraph has in no case been split up into anything which possesses a smaller mass, and since it is the lightest particle ever found to carry a positive charge, it may be properly designated as the *positive electron,* especially since atomic weights indicate strongly that the heavier atoms are built up of hydrogen.

4. THE PRINCIPLE OF ELECTRICAL NEUTRALITY.

It has been found by experiment that material bodies at ordinary temperatures are not in general set in motion by being placed in a uniform electrical field, or they are in the state which is commonly designated as uncharged. Since, however, electrically charged particles can be obtained from all such bodies, it has been concluded that the " uncharged " condition does not indicate that they do not contain electric charges, but rather that the positive and negative electricity are present in each uncharged body in equivalent amounts, a condition which is designated by the term electrically neutral. This idea of electrical neutrality is in accord

with the Faraday ice-pail experiment mentioned in an earlier paragraph, and has been extensively used in the study of aqueous solutions of electrolytes. Thus in a salt solution it is considered that the number of equivalents of negative ions present in any solution is equal to the number of equivalents of positive ions.

The idea of electrical neutrality has been utilized in all of the prevalent theories of the structure of the atom. Thus the number of elementary positive charges in any complete atom is supposed to be equal to the number of elementary negative charges. If it is supposed that these elementary charges are due to the presence of electrons, this would mean that *the number of positive electrons in any atom is equal to the number of negative electrons.* Any atom which is not electrically neutral is designated as an ion, and may be charged either with a net negative or a net negative charge. In an ion the number of positive electrons is in no case equal to the number of negative electrons.

One positive plus one negative electron may be designated as an *electron pair,* which may be indicated by the symbol *p,e.* Here *p* represents a positive, and *e* a negative, electron, and the comma is used when it is not assumed that there is a definite union between the two. The symbol *pe* will be used to represent a neutron, or a positive and a negative electron in an extremely close combination.

While the atomic weight of the electron pair which constitutes the hydrogen atom is 1.0078, it has been stated that the mean atomic weight of an *electron pair* in any other atom is very close to 1.000. *Thus the atomic weight of any species of atoms gives the number of electron pairs in each of its atoms,* so the atomic weight of oxygen, 16, indicates that the oxygen atom consists of 16 electron pairs, that is, of 16 positive and 16 negative electrons, and its formula is $p_{16}e_{16}$. Calcium [5] with an atomic weight of 40 is $p_{40}e_{40}$, while the principal atomic species of the element argon has also an atomic weight of 40, and is also $p_{40}e_{40}$. *Thus calcium and this argon are isomeric atomic species.* The term isomeric indicates that they are represented by the same formula, and thus contain the same number of negative and also the same number of positive electrons. That such atoms should be designated as isomeric was proposed by the writer several years ago. The term is certainly preferable to *isobaric,* which is sometimes

[5] This refers to the most abundant isotopes.

used, since the latter term indicates only that the atomic weights are the same, *which may not be strictly true,* while the term isomeric expresses not only that the atomic weights are very close to the same whole number but also the identity with respect to the number of each type of electron present, as expressed above. The nuclei of *isomeric* atoms are nearly *isobaric* and are not isomeric.

5. THE NUCLEAR ATOM.

The prevalent idea of the atom is that it consists of a minute nucleus surrounded by a system of negative electrons. This nucleus is supposed to contain practically all of the mass, and also all of the positive electricity of the atom. An atom of this type is sometimes designated as a solar system, in which the nucleus takes the place of the sun, and the planets are represented by negative electrons, which may be called planetary electrons. These electrons and the nucleus are supposed to be at somewhat the same relative distances in comparison with their dimensions as the planets and the sun.

This type of atom was first suggested in 1903 by Nagoaka,[6] but the evidence for it is due largely to Rutherford.[7] According to the earlier suggestion of Lord Kelvin[8] and of J. J. Thomson, the positive electricity in an atom is distributed in a diffuse sphere or disc, but Rutherford discovered certain facts, described in the following paragraph, which did not seem to be in harmony with this idea.

When radium and certain other radioactive substances disintegrate, they emit alpha particles. These alpha particles carry two elementary positive charges of electricity, their mass is 4 or that of the helium atom, and they travel at high speeds, as great as 20,000 miles per second. Now Rutherford and his collaborators —Geiger, Marsden, and Darwin—found that when these alpha particles are shot through various substances, such as hydrogen or gold, the alpha particles are occasionally deflected with extreme sharpness, and even turned back almost directly in their path. In general the path is that of one limb of an hyperbola, and by considering the simple mathematical relations of such a path they

[6] Nagoaka: *Phil. Mag.*, **7**, 445 (1904).
[7] Rutherford: *Ibid.*, **21**, 669 (1911), and later papers.
[8] Kelvin: *Phil. Mag.*, **3**, 257 (1902).

were able to show that the positive electricity in an atom is concentrated in a small nucleus and to make an approximate calculation of the diameter of this nucleus. It was found that the maximum diameter of the nucleus of a gold atom is 6.8×10^{-12} cm.; while that for the hydrogen nucleus is 1.7×10^{-13} cm. Since an atom is of the order of 2×10^{-8} cm. in diameter, this indicates that the atom has a diameter from 2000 to 100,000 times that of the nucleus, or its volume is from a few million to several billion times as great. The diameter of the negative electron is usually given as 2.0×10^{-13} cm., so the nucleus of an atom seems to be of somewhat the same size as the electron. It is not unlikely that the hydrogen nucleus may be smaller than the electron, but it seems probable that all other atom nuclei are somewhat larger. Evidence will be presented later, which seems to indicate that while the hydrogen nucleus does not contain a negative electron (being itself presumably the positive electron) all other nuclei of stable atoms contain two or more negative electrons.

6. EVIDENCE FOR THE PRESENCE OF NEGATIVE ELECTRONS IN ATOM NUCLEI.

Since the nucleus of an atom may be defined as that part in which the positive charge resides, it would seem evident that the positively charged alpha particles, which are emitted at high speed by radioactive atoms, must come from the nucleus. Certain radioactive substances, instead of emitting alpha particles, eject beta particles or negative electrons at speeds which closely approach the velocity of light, and rise as high as 180,000 miles per second. On account of the considerable energy which they possess Rutherford concluded that these negative electrons cannot come from the non-nuclear system of electrons, but must be thrown out by the nucleus itself. Even better evidence than this that both the alpha and beta particles are ejected from the nucleus is given by the change which occurs in the chemical and physical properties of the elements, and the change of the atomic number which accompanies such phenomena. These will be described later in detail. Since the evidence given by the radioactive elements relates only to the heaviest elements, it may be seen that it might be possible that light nuclei do not contain negative electrons. Thus Nicholsen considered that the alpha particle consists of two hydrogen nuclei, each with a unit positive charge, and that the mass 4 of the helium nucleus is due to a squaring of the mass

due to the proximity of like charges. It will be found, however, that it is much simpler to assume that the alpha particle (helium nucleus) consists of 4 positive and 2 negative electrons.

7. EXPLANATION OF THE PACKING EFFECT AS DUE TO ELECTROMAGNETIC MASS.

According to the electromagnetic theory of Lorentz the mass of an electron increases with its velocity, so at least a part of its mass appears concomitantly with the appearance of kinetic energy. In the special relativity theory mass and energy are identical, but are expressed in different units. The idea of the equivalence of mass and energy may be used in explaining the packing effect.

If a stone falls to the earth its potential energy, due to its position, disappears, and just this amount of energy reappears in other forms, mostly as heat, when the stone strikes the ground. When a positive and a negative electron are relatively far apart as in a hydrogen atom, the mass of the electron pair is 1.0078. If, however, due to their mutual attraction the positive and the negative electron were to fall closer together, a part of the original potential energy, due to their attraction at a distance, would disappear, and this amount of energy would be given off in some way, presumably as a form of radiation. The energy given off would be equal to 0.0078 units of mass, so the resulting neutron (*pe*) would have a mass of 1.000. While there is at present no indication that such a simple system will do this, it seems probable that four positive electrons will under some circumstances unite with two negative electrons to form an alpha particle (helium nucleus), and this would then pick up two additional non-nuclear electrons to form a neutral helium atom. The difference in mass between four hydrogen atoms and one helium atom, amounts to a decrease of 0.77 per cent., or the magnitude of the packing effect.

While the writer was working in the endeavor to show definitely that the packing effect could be due to electromagnetic effects, Rutherford[9] made the suggestion that there *might be* such an effect in the formation of helium, as is indicated by the two following paragraphs:

> The exceedingly small dimensions found for the hydrogen nucleus add weight to the suggestion that the hydrogen nucleus is the positive electron, and that its mass is entirely electromagnetic in its origin.

[9] *Phil. Mag.*, **27**, 494–5 (1914).

For the dimensions of the positive and negative electrons considered, the packing must be very close in order to produce an appreciable alteration in the mass due to this cause. This may, for example, be the explanation for the fact that the helium atom has not quite four times the mass of the hydrogen atom.

Comstock had previously [10] suggested that the absence of exact relations among the atomic weights might be due to differences in the velocities of the electrons, but he explained only the deviations from whole numbers on the oxygen basis in this way. These deviations do not need to be explained since they are plainly due to the existence of isotopes, and the deviation between hydrogen and helium is too great to be explained in this way. Nevertheless, Comstock's paper deserves attention as a beginning in the application of the ideas of the electromagnetic theory to this field.

Harkins and Wilson made certain preliminary calculations which seemed to indicate that when a positive electron approaches a negative electron the loss of mass might amount to as much as 0.77 per cent., which is the value of the experimental packing effect. The actual solution of the problem was carried out for them by Prof. A. C. Lunn, of the Department of Mathematics, University of Chicago, and will be given in a later section. Only an approximate solution was attempted, since it seems likely that the inverse square law does not hold at such minute distances as those between the positive and negative electrons in a complex nucleus. According to Professor Lunn's calculation, based on the simplifying assumption of point charges, the change of mass, or packing effect, due to the overlapping of the electromagnetic fields of two electrons is

$$\Delta = m \pm \frac{e^2}{2\pi c^2 d} \qquad (1)$$

in Heaviside units. In this equation Δm is the change of mass, e is the charge on the electron, c the velocity of light, and d is the distance between the centres of the electrons. The $\pm$ sign indicates that the mass increases if the two electrons have like charges, but decreases when they are oppositely charged. Since it may be expected that in a complex system the electrons will arrange themselves so that electrons of unlike charge lie closest together,

[10] *J. Amer. Chem. Soc.*, **30**, 683 (1908).

the effect to be expected is a decrease of mass, as in accord with the experimental data.

The longitudinal mass of an electron is

$$m = \frac{e^2}{6\pi c^2 R} \qquad (2)$$

where R is the radius of the electron.

By division of (1) by (2)

$$\frac{\triangle m}{m} = \frac{3R}{d}. \qquad (3)$$

Since only the positive electron has an appreciable mass, R may be taken as the radius of the positive electron. Equation 3 then states that for a change of mass of 1 per cent., $\frac{\triangle m}{m} = 0.01$, or $\frac{3R}{d} = 0.01$, so $d = 300R$, or the distance between the centres of the electrons should be 300 times the radius of the positive electron. For a packing effect of 0.77 per cent. it is evident that the distance between centres should be approximately $400R$. This would make it seem plausible that the packing effect of 0.77 per cent. is due to an electromagnetic mass effect.

In conversation with the writer, Silberstein has claimed that when the distribution of charges in the electrons is taken account of, the change of electromagnetic mass is too small to account for the considerable magnitude of the packing effect, since the latter is so great as to make it necessary that the positive electron shall lie partly inside the negative one. According to equation 2 given above, which may not be entirely correct, the positive electron should have a radius only 1/1835 that of the negative electron, since the radius is inversely proportional to the mass. It seems to the writer the probability that the packing effect is due to electromagnetic mass effects is not decreased by a consideration of Doctor Silberstein's equations, since:

1. The equations in any event are only approximate.
2. The equations are based on the inverse square law, which is believed by the writer to be very likely to fail at such minute distances. Rutherford's experiments seem to indicate that this law fails very close to the nucleus.
3. The positive electrons may lie in indentations in the negative electrons.
4. We have no evidence that the positive electrons may not lie partly or wholly within the negative electrons.

5. Deformations of either the positive or the negative electrons would affect the packing effect. If, for example, it is assumed that the attraction between the positive and negative electrons not only draws them close together, but that it also causes the charges of the two electrons of opposite sign to become concentrated largely at their region of contact, it is easily seen that the resulting decrease of electromagnetic mass might be very much greater than the packing effect actually found (0.77 per cent.). As has already been stated, it is obvious that the important factor is the loss of mass of the positive electron, since the mass of the negative electron is too small to be greatly decreased.

While nothing has been said in the preceding paragraphs of the effect of the velocities of the electrons in producing slight variations of the packing effect, it is not improbable that such effects may exist to an extent which would be detectable by very delicate measurements, but it is evident that the loss of mass of 0.77 per cent. cannot be due to such a cause, since in the hydrogen atom neither the positive nor the negative electron is moving with a sufficient velocity to give an appreciable mass due to this cause. It is evident that any mass change of this type must be represented by a higher mass in the complex atoms.

8. THE ATOMIC NUMBER GIVES THE CHARGE ON THE NUCLEUS AND THE NUMBER OF NUCLEAR ELECTRONS.

In 1911 Barkla,[11] from his work on the passage of X-rays through matter suggested that the positive charge on the nucleus of the atom is about half the atomic weight. Now the ordinal number of an element in the periodic system, as first given by Rydberg in 1896, is approximately half the atomic weight, so this suggested to van den Broek that the ordinal number of the element gives the number of elementary positive charges on the nuclei of its atoms. Van den Broek [12] designated this as the atomic number, which is the term now in use, though it is much less exact than that used by Rydberg.

The suggestion of van den Broek was strongly supported by the remarkable work of Moseley on the X-ray spectra of the

[11] Barkla: *Phil. Mag.*, **21**, 648 (1911).
[12] van den Broek: *Physik. Z.*, **14**, 33 (1913).

elements. Using a method first suggested by Laue [13] and Bragg,[14] Moseley [15] and Darwin developed an experimental method for determining the X-ray spectra of the elements by reflection from a crystal surface. When an element is used as an anti-cathode in an X-ray tube it emits characteristic radiations of a frequency roughly 1000 times that of ordinary light. Each element was found by Moseley to be characterized by two different classes of radiation, the K series, with the highest frequency, and the L series, with a lower frequency. Other series of still lower frequency have since been found. The K series showed in Moseley's photographs as consisting of two lines, an alpha and a beta line, and these were used by him for most of his calculations. More lines were found in the L series.

The remarkable feature of Moseley's photographs is that they show that the frequency of the K series lines constantly increases in a very regular way as the atomic number increases.

He found the frequency (ν) to be a linear function of the square of the atomic number (M), sometimes called the Moseley number, according to the following simple equation:

$$\nu = K(M-1)^2$$

It is seen that the frequency of the radiation increases as the atomic number increases. Now if the atomic number represents the positive charge on the nucleus, this may be explained very simply. According to the theory of Bohr ordinary light is due to the falling of an electron from an outer orbit in an atom to one slightly closer to the nucleus. In the same way the K series of X-rays may be explained as due to the falling of an electron into the orbit closest to the nucleus from an orbit farther out. The frequency of the light emitted is supposed to be proportional to the energy of the fall. In comparable falls, that is between orbits of the same number in different atoms, as, for example, a fall from orbit 2 to orbit 1, the energy of the drop should increase with the magnitude of the attractive force between the electron and the nucleus, that is, with the charge of the nucleus. While the above description of Bohr's idea is too brief to be accurate,

[13] Laue: *Ann. Physik.*, **41**, 989 (1913).

[14] W. Bragg and L. Bragg: *Proc. Roy. Soc.*, **88A**, 428 (1913), **89A**, 246 (1914).

[15] Moseley: *Phil. Mag.*, **26**, 1024 (1913); **27**, 703 (1914).

it may give a slight idea as to the meaning of Moseley's work. Either Bohr's papers or Sommerfeld's "Atombau" should be consulted for a more accurate description of the theory.

Since the atom is supposed to be electrically neutral, the number of planetary negative electrons should be equal to the atomic number (M).

9. RADIOACTIVITY: THE SPONTANEOUS DISINTEGRATION OF ATOMS.

Early in 1896 Becquerel became interested in the new penetrating X-rays just discovered by Röntgen, and especially in the statement of H. Poincare that these rays are given off from the fluorescent spot on the glass produced by the cathode rays. It occurred to Becquerel to try an experiment to see if substances which are phosphorescent after their exposure to ordinary light give similar penetrating rays. Using a potassium-uranium double salt he was able to get such rays, which passed through paper and aluminium and affected a photographic plate. Later experiments showed, however, that the same effect was produced if the salt was not previously exposed to light. It was soon found that the phenomenon was not due at all to the fact that the salt was phosphorescent, but that it is a property of the element uranium.

About two years later Madame Curie discovered polonium and radium which exhibit the same phenomenon, but very highly intensified. Substances of this type are considered to be radioactive. In 1902 Rutherford classified the rays given off by such substances as follows:

1. Alpha rays, which are slightly but not greatly deviated by a magnet or by an electric field, and consist of particles which carry a double positive charge, and have the mass of a helium atom. It was afterward found that the alpha particle is the nucleus of the helium atom.

2. Beta rays, which consist of negative electrons, and are much more greatly deviated by either an electric or a magnetic field. They penetrate much greater thicknesses of material than alpha rays, that is, their range is much greater.

3. Gamma rays, which are not deviated by a magnet and carry no charge. These are very similar to extremely "hard" or penetrating X-rays, and they penetrate much greater thicknesses of material than either alpha or beta rays.

As has been stated in an earlier paragraph, both the alpha and

beta particles are shot out at high speeds from the nucleus of the atom.

So far as is now known, a single atom never ejects more than a single alpha or a single beta particle at one time, and in no known case do both an alpha and a beta particle escape at once. In general, a certain species of atoms exhibits only one of the two classes of disintegration. Thus, for example, ionium, radium, radium emanation, radium A, radiothorium, and a number of others emit only alpha particles; while uranium X_I, uranium X_{II}, mesothorium I and II, radium C_2, radium E, etc., give off beta particles. A few species of atoms, such as radium C and thorium C, may disintegrate in either way, but a single atom disintegrates in only one of the two ways. For example, 99.97 per cent. of the atoms of radium C disintegrate by shooting out beta particles, and 0.03 per cent. by the emission of alpha particles.

There are three disintegration series—the uranium, the actinium, and the thorium series. The uranium series consists of uranium and about sixteen other atomic species, of atomic number from that of uranium (92) to that of thallium (81). All of these are formed by a series of one to fourteen disintegrations from the original ancestor, uranium. The ancestor in the thorium series is thorium, and for the actinium series is unknown. It is usually supposed that the actinium series is a branch from the uranium series. All three of the series begin to branch in the region of atomic number 82.

Figure 1 gives a diagrammatic representation of all three series, and is a modified form of a diagram given by Soddy. It will be seen that in an alpha change, represented by a long, heavy arrow pointing downward, the atomic number, and also the valence is decreased by two. In the ordinary form of the periodic system there is a change of two places to the left. In a beta change, represented by a short arrow pointing diagonally upward, the atomic number and valence increase by one, and the element moves one place to the right in the ordinary periodic table. These relations to the periodic system were discovered by Fajans, Soddy, Russell, von Hevesy, and Fleck.

The formulæ given inside the rectangles in Fig. 1 are those which are valid for the nucleus of the atom, provided that each nucleus is built as completely as possible of alpha particles and electrons. In these formulæ ∞ represents an alpha particle, h

a hydrogen nucleus or positive electron, and e a negative electron. Since it is assumed that each alpha particle consists of four positive and two negative electrons, it is apparent that there are a great many electrons present in the nuclei which are not indicated by the letter e. The electrons represented by this symbol may be styled "*cementing electrons*" while those in the alpha particles may be called "*binding electrons.*"

The figure gives also the average life of most of the atomic species. Thus the average life of an uranium atom is 8×10^9 years, while that of a thorium C′ atom is 10^{-11} seconds. Thorium has the greatest average life, 2.5×10^{10} years, of any of the radioactive substances listed. All three of the radioactive series are usually supposed to end in lead, since the radioactivity of lead of atomic weights 206 and 208 and of all lighter atoms, with the possible exception of potassium and rubidium, is so slight, that it has not been detected.

10. ISOTOPES.

About ten years ago a number of workers in the subject of radioactivity, among them Soddy and Fajans, began to realize that when they endeavored to fit the radioactive elements into the periodic system of Mendelejeff, there were more elements than there were places into which they could be fitted, as is illustrated by Fig. 1. However, it was found that in a number of cases a number of these elements, though their atomic weights were apparently different, appeared to have identical chemical properties, and aside from their density, appeared to have also identical physical properties. To designate a set of elements which were thus alike in properties, Soddy proposed to use the word isotopes (iso — tope = same place). While each isotope is essentially a different element, chemists and physicists were so used to considering all of the simple materials which behave alike chemically and have a certain atomic number, as constituting one element, that in spite of such differences in atomic weight all of the different atomic species of this type (isotopes) have come to be considered as a single element.

That isotopes usually have different atomic weights was apparent from the disintegration relations of the radioactive elements as exhibited in Fig. 1,[16] and was proved by direct atomic weight determinations made on the isotopes of lead by Soddy and by

[16] Fig. 1 indicates the presence of seven isotopes of polonium, four of radium, and ten of lead.

Richards. The latter showed that the atomic volumes of these isotopes are the same within the limits of error of very careful experiments. The first and only chemical characteristic in which isotopes have been found to differ was discovered in an investigation suggested by the writer [17] and carried out by Aronberg, with the aid of suggestions by Professor Gale in regard to the spectroscopic technic. It was found that the wave-length of the line $\lambda 4058$ in lead from radium (RaG) of atomic weight 206.33 is one ten-thousandth of 1 per cent. greater than that produced by ordinary lead of atomic weight 207.2. This result was afterward confirmed by Merton. It is apparent that the chemical and spectroscopic differences are small, but they may be of importance among the light elements where the atomic weight differences between isotopes rise to 16 per cent.*

II. THE HELIUM-HYDROGEN THEORY OF ATOMIC CONSTITUTION.

A definite helium-hydrogen system of atomic constitution was published by Harkins and Wilson [18] in the year 1915.† The first part of the present paper indicates that all of the atoms other than that of hydrogen itself, are intra-atomic compounds of hydrogen. The number of hydrogen atoms in any complex atom is given by the atomic weight of the latter on the basis of oxygen as 16. Thus the atomic weight 40 for calcium indicates that the ordinary calcium atom is H'_{40}, where the prime is used to indicate that the compound is intra-atomic and not molecular. However, since the hydrogen atom consists of one positive electron or proton (p) and one negative electron (e), this indicates that the general formula of the calcium atom is $p_{40}e_{40}$. However, in the formation of such an atom, while *all* of the protons enter the nucleus, only *half* of the electrons enter it, and the other half become planetary electrons, so the formula of the atom becomes $(p_{40}e_{20})\ e'_{20}$ where the parenthesis indicates the nucleus, and the planetary electrons are indicated by a prime.

It is of great interest that in the formation of light atoms

[17] Harkins and Aronberg: *Proc. Nat. Acad. Sci.*, **3**, 710–15 (1917); Aronberg: *Astrophys. J.*, **47**, 96–103 (1918); Harkins and Aronberg: **42**, 1328–1335 (1920).

* The difference found by Harkins and Aronberg is not that predicted by the Bohr theory but is about fifty times larger.

[18] *J. Am. Chem. Soc.*, **37**, 1383–95 (1915).

† A helium disintegration theory was suggested in 1913 by van den Broek, but his theory was much less definite, and was based upon the existence of a much larger number of elements.

just one-half of the negative electrons enter the nucleus (of the most abundant atomic species of the element), except that when the total number of negative electrons is odd and is not divisible by two the number of electrons entering the nucleus is the next whole number above one-half the number of protons. *Now this relation as it exists for the atoms of even atomic number is just that found in the helium atom, since helium is* $(p_4e_2)\ e'_2$, *that is just one-half of the negative electrons in the atom are found in the nucleus.*

The atomic weights of the light elements, taken together with their atomic numbers, give definite evidence that the nuclei of light atoms of even atomic number are built up almost wholly from alpha particles. Thus, beginning with carbon of atomic number 6, and up to iron of atomic number 26, the chemical atomic weight indicates that in every case the most abundant isotope has an atomic weight which is divisible by four, when the atomic number is divisible by two: that is both the mass and the charge are multiples by a whole number of those of the alpha particle, as is shown in Table III, in which *a* represents an alpha particle and *e* a negative electron.

TABLE III.

Evidence of the Atomic Weights and Atomic Numbers that the Nuclei of the Atoms of the Light Elements Are Built Up Largely of Alpha Particles.

Atomic Number.	Atomic Weight.	Composition of Nucleus Indicated.
$6 = 3 \times 2$	$12 = 3 \times 4$	a_3
$8 = 4 \times 2$	$16 = 4 \times 4$	a_4
$10 = 5 \times 2$	$20 = 5 \times 4$	a_5
$12 = 6 \times 2$	$24 = 6 \times 4$	a_6
$14 = 7 \times 2$	$28 = 7 \times 4$	a_7
$16 = 8 \times 2$	$32 = 8 \times 4$	a_8
$18 = 9 \times 2$	$40 = 10 \times 4$	$a_{10}e_2$
$20 = 10 \times 2$	$40 = 10 \times 4$	a_{10}
$22 = 11 \times 2$	$48 = 12 \times 4$	$a_{12}e_2$
$24 = 12 \times 2$	$52 = 13 \times 4$	$a_{13}e_2$
$26 = 13 \times 2$	$56 = 14 \times 4$	$a_{14}e_2$

The hydrogen-helium system may also be presented in the form of a table which gives the *composition* of the light atoms, as in Table IV.

It is of interest to note that this table was published four years before the discovery of isotopes among any of the light elements, with the single exception of the isotope of neon, whose existence

was doubtful at that time. While the table was given the form of the chemical periodic system, it was specifically pointed out that the composition and stability of the nucleus are not related

TABLE IV.

The Helium-Hydrogen Composition of the Most Abundant Isotope of Each of the Light Elements as Presented in 1915 by Harkins and Wilson.

H = 1.0078.

	0.	1.	2.	3.	4.	5.	6.	7.	8.	
Ser. 2.	He He	Li He+H_3	Be 2He+H	B 2He+H_3	C 3He	N 3He+H_2	O 4He	F 4He+H_3		
Theor.	4.00	7.00	9.0	11.0	12.00	14.00	16.00	19.00		
Det.	4.00	6.94	9.1	11.0	12.00	14.01	16.00	19.00		
Ser. 3.	Ne 5He	Na 5He+H_3	Mg 6He	Al 6He+H_3	Si 7He	P 7He+H_3	S 8He	Cl 8He+H_3		
Theor.	20.0	23.00	24.00	27.0	28.0	31.00	32.00	35.00		
Det.	20.0	23.00	24.32	27.1	28.3	31.02	32.07	35.46		
Ser. 4.	A10He	K 9He+H_3	Ca 10He	Sc 11He+H	Ti 12He	V 12He +H_3	Cr 13He	Mn 13He +H_3	Fe 14He	Co 14He +H_3
Theor.	40.0	39.00	40.00	45.0	48.0	51.0	52.0	55.00	56.00	59.0e
Det.	39.9	39.10	40.07	45.1	48.1	51.0	52.0	54.93	55.84	58.97

Increment from Series 2 to Series 3 = 4He
Increment from Series 3 to Series 4 = 5He (4He for K and Ca)
Increment from Series 4 to Series 5 = 6He

at all directly to this form of periodicity. The periodicity which is involved will be discussed later in the present paper, since it is of fundamental importance in connection with the study of the stability of atom nuclei.

It is evident that Table IV may indicate only that the light atoms have been *built up* largely from alpha particles (He nuclei), and that, taken alone, it does not prove that the alpha particles actually preserve their existence in the complex nuclei. The question of their presence in such nuclei will be discussed later.

12. THE NEW PERIODIC SYSTEM.

Classification of the Elements into (1) *Elements of Even Atomic Number,* and (2) *Elements of Odd Atomic Number.*

If only the most abundant isotope of each light element is considered, it is seen that the atom nuclei of the atomic species of even atomic number may be represented as built up of alpha particles, either alone or as the atomic weight increases, with the inclusion of (usually two) negative cementing electrons. However, it is apparent that this cannot be done in the case of the elements of *odd* atomic number, in which there is usually present

a proton-electron *group* consisting of three protons and two electrons (p_3e_2), as is shown in Table V.

TABLE V.

Composition of Light Atoms.

(Only the most abundant isotope of each element is represented.)

Atoms of Even Nuclear Charge.						Atoms of Odd Nuclear Charge.					
At. No.	Symbol.	Formula of		Non-nuclear Electrons.		At. No.	Symbol.	Formula of		Non-nuclear Electrons.	
		Atom.	Nucleus.	Inner.	Valence.			Atom.	Nucleus.	Inner.	Valence
2	He...	He	α	e_2	..	3	Li...	HeH_2	$\alpha(p_3e_2)$	e_2	e
4	Be ..	He_3H	αpe	e_2	e_2	5	B....	He_2H_3	$\alpha_2(p_3e_2)$	e_2	e_3
6	C ...	He_3	α_2	e_2	e_4	7	N....	He_3H_2	$\alpha_3(p_3e)$	e_2	e_5
8	O....	He_4	α_4	e_2	e_6	9	F....	He_4H_3	$\alpha_4(p_3e_2)$	e_2	e_7
10	*Ne*...	He_5	α_5	e_{10}	..	11	Na...	He_5H_3	$\alpha_5(p_3e_2)$	e_{10}	e_1
12	*Mg*..	He_6	α_6	e_{10}	e_2	13	Al...	He_6H_3	$\alpha_6(p_3e_2)$	e_{10}	e_3
14	*Si*...	He_7	α_7	e_{10}	e_4	15	P....	He_7H_3	$\alpha_7(p_3e_2)$	e_{10}	e_5
16	S	He_8	α_8	e_{10}	e_6	17	*Cl*...	He_8H_3	$\alpha_8(p_3e_2)$	e_{10}	e_7
18	A....	He_{10}	$\alpha_{10}e_2$	e_{18}	..	19	K ...	He_9H_3	$\alpha_9(p_3e_2)$	e_{10}	e_1
20	Ca...	He_{10}	α_{10}	e_{18}	e_2	21	Sc...	$He_{11}H$	$\alpha_{11}e_2p$	e_{18}	e_3
22	Ti....	He_{12}	$\alpha_{12}e_2$	e_{18}	e_4	23	V....	$He_{11}H_3$	$\alpha_{12}e_2(p_3e_2)$	e_{18}	e_5
24	Cr....	He_{13}	$\alpha_{13}e_2$	e_{18}	e_6	25	Mn..	$He_{12}H_3$	$\alpha_{13}e_2(p_3e_2)$	e_{18}	e_7
26	Fe....	He_{14}	$\alpha_{14}e_2$	e_{18}	e_8	27	Co...	$He_{13}H_3$	$\alpha_{14}e_2(p_3e_2)$	e_{18}	e_9

It is evident that when only the most abundant isotope is considered there is a *periodicity of two* in the composition of the atoms, as contrasted with the periodicities of 8, 18, and 32 in the ordinary periodic system of Mendelejeff. This periodicity of 2 relates to the nucleus, while those of the ordinary system refer to the arrangement of the planetary electrons in the atom. Since the characteristics of the nucleus are not apparent in the chemical or physical properties of the elements with the exception of the property of mass, it is not to be expected that the periodicity here presented shall be apparent in any of the chemical or physical properties of the elements.

13. THE NEW PERIODIC SYSTEM AND THE STABILITY AND ABUNDANCE OF THE ELEMENTS.

The considerations involved in relating the above periodicity to the abundance of the elements will be presented in the form of a quotation from an earlier paper:

It might be expected, however, that the composition of the nucleus should affect its own stability, which from radioactive evidence means the stability of the atom. From this standpoint it might be reasonable to suppose that the

atoms of one of the series, the even or the odd, should be more stable than those of the other. Now, unfortunately, there is no known method of testing the stability of the lighter atoms, but it might seem, at least at first thought, that the more stable atoms should be the more abundantly formed, and to a certain extent this is undoubtedly true. If then, at the stage of evolution represented by the solar system, or by the earth, it is found that the even-numbered elements are more abundant than the odd, as seems to be the case, then it might be assumed that the even-numbered elements are on the whole the more stable. However, there is at least one other factor than stability which must be considered in this connection. The formula of the even-numbered elements has been shown to be $n\mathrm{He}'$. Now, since the formula for the odd-numbered elements is $n\mathrm{He}' + \mathrm{H}'_3$, it is evident that, if the supply of H_3 was relatively small at the time of their formation, not so much material would go into this system. This would be true whether the H_3 represents three atoms of hydrogen or one atom of some other element.[19]

In studying the relative abundance of the elements the ideal method would be to sample one or more solar systems at the desired stage of evolution, and to make a quantitative analysis for all of the ninety-two elements of the ordinary system. Since this is impossible, even in case of the earth, it might be considered that sufficiently good data could be obtained from the earth's crust, or the lithosphere.

However, there are several important factors which cause our knowledge of the quantitative composition of the earth's crust to be of much less value for the solution of our problem than it might seem to possess on first thought. In the first place the quantitative analyses which have been made represent the composition of only the mere skin of the earth, the depth of which does not exceed the ten to twenty miles caused by geologic displacements. The surface of the earth has been markedly influenced both by igneous processes which have resulted in magmatic differentiation, and by weathering, solution, and redeposition. For example, the common idea that sodium is a very abundant element undoubtedly has its origin in the fact that the solubility of its salts has caused their very considerable concentration in the oceans. Again, the fact that the salts of sodium are much more fusible than similar salts of the alkaline earths and most other metals in the rocks, has probably caused it to be segregated by magmatic solution and redeposition. Thus, while in the average igneous rock found on the surface of the earth there seems to be about 2.23 per cent. of sodium, it is not improbable that this is a larger percentage than would be found if the whole material of the earth could be taken as a sample for analysis.

If the sun is next considered it is found that although a large amount of its surface is exposed to us for spectroscopic investigation, the spectroscope gives no accurate measure of the quantitative composition, and that its findings are largely influenced by the height in the gaseous envelope of the sun at which the observation is taken.

[19] The formula of the nucleus corresponding to H_3 is $(p_3\epsilon_2)+$ which would be an isotope of hydrogen. The ratio of negative to positive electrons in this group is $2/3$, a much higher ratio than is found for any of the light atoms. This seems to indicate that the existence of independent nuclei of this type is improbable. Also Aston has failed to find any evidence of the existence of this isotope in hydrogen.

14. THE COMPOSITION OF METEORITES AS RELATED TO THE STRUCTURE OF COMPLEX ATOMS.

There is, however, material available of which accurate quantitative analyses can be made, and which falls upon the earth's surface from space. The bodies which fall are called meteorites, and no matter what theory of their origin is adopted, it is evident that this material comes from much more varied sources than the rocks on the surface of the earth.[20]

In any event, it seems probable that the meteorites represent more accurately the average composition of material at the stage of evolution corresponding to the earth than does the very limited part of the earth's material to which we have access. At least it might seem proper to assume that the meteorites would not exhibit any special fondness for the even-numbered elements in comparison with the odd, or *vice versa*, any more than the earth or the sun as a whole, at least not unless there is an important difference between these two systems of elements, which is just what it is desired to prove.

A preliminary study of the *most recent analyses* of meteorites of different classes showed that, either for any one class or for the meteorites as a whole, *the even-numbered or helium system elements are very much more abundant than those of the odd-numbered or helium-hydrogen system.* For a more detailed study use was made of the older but much more complete and more valuable data collected by Farrington,[21] who suggests that the average composition of meteorites may represent the composition of the earth as a whole.

The results obtained by averaging the analyses of 318 iron and 125 stone meteorites, 443 in all, show that the first seven elements in order of abundance are oxygen, iron, nickel, silicon, magnesium, sulfur, and calcium; and *not only do all of these elements have even atomic numbers, but in addition they make up 98.6 per cent. of the material of the meteorites.* Of the remaining elements present to a great enough extent to have an appreciable effect upon the percentage values, seven are odd and five are even, but in all only 1.22 per cent. are odd numbered, while 98.78 per cent. are even. Of the iron meteorites, 99.22 per cent. of the material is made up of even-numbered elements, and of the stone meteorites, 97.59 per cent.

[20] Perhaps the theory of origin of the meteorites most in accord with their characteristics is that they are fragments of larger solid bodies, such as planets or planetesimals. Meteorites are known to vary in magnitude from the size of dust particles up to 36½ tons, though it is probable that much larger individuals than this maximum may have fallen. Their density varies from less than two to more than eight and one-half. In chemical composition they are much more closely related than the rocks on the surface of the earth, which seems to indicate that the parent bodies were much less affected by differentiative processes. If meteorites have been formed by the scattering of a very large body or bodies, it is evident that a relatively small portion of the material is derived from what may be called the crust, so that a very small part of the material would have been affected by weathering even if the parent bodies had atmospheres. However, whether this is true or not, evidence of weathering has not thus far been obtained. Meteorites may be classified in the three main divisions, iron, ironstone and stone meteorites, but much more elaborate classifications are found useful in showing the gradations by which one of these systems passes into the other. The fact that the substance of the iron and the stone meteorites passes gradually from one class into the other, that the nickel-iron and pyrrhotite of the stone is the same as that of the iron meteorites, and that the silicates of the stone meteorites gradually diminish in percentage amount as they grade over into iron meteorites, seems to suggest strongly that these different classes were originally present in some cosmic mass or masses, in which the materials were assorted according to their specific gravity. In such a body the lighter stony material would very probably be nearer the surface, and would therefore cool more quickly, while the nickle-iron would lie nearer the centre and would on this account cool very slowly. The physical properties of the two classes of meteorites seem to indicate that they have been cooled in just such a way.

[21] Farrington, *Publications* 120 and 151, Field Columbian Museum, Chicago, "Meteorites," 205 (1915); I. *Geol.*, 9, 623 (1901); Bvisse, *Mem. Soc. Lits. Sci. Arts l'Aveyron*, 7, 168; Meuner, "Cours. de Geol. Comparee; " Suess, "The Face of the Earth," (English translation), Vol. 4, p. 543.

TABLE VI.

*Average Composition of Meteorites, Showing the Predominance of the Even-numbered Elements, and of the Elements of Low Atomic Number.**

At. no.	Element.	Percentage by weight. Stone meteorites. 125 analyses. Even.	Odd.	99 analyses. Even.	Odd.	Weight percentage. 53 stone meteorites.* Even.	Odd.	Atomic percentage. 125 stone meteorites. Even.	Odd.	Weight percentage. Average of 318 iron and 125 stone meteorites. Even.	Odd.	Atomic percentage. Even.	Odd.	Atomic percentage. 318 iron meteorites. Even.	Odd.	Atomic percentage. 350 stone to 10 iron meteorites.† Even.	Odd.
1.	Hydrogen	...	..	...	..	..	0.084	...	..	...	..	..	...	...	..	...	..
2.		...	..	...	..	..	Trace	...	..	...	..	...	...	...	..	...	..
3.	Lithium	...	..	...	..	..	...	...	..	...	..	...	...	...	..	...	..
4.		...	..	...	..	...	...	...	..	...	..	...	...	...	..	...	..
5.		...	..	...	..	...	...	...	..	...	..	...	...	...	..	...	..
6.	Carbon	0.06	..	...	..	0.150	...	0.12	..	0.04	..	0.14	...	0.03	..	0.12	..
7.	Nitrogen	...	..	...	..	..	...	...	..	...	..	...	...	...	..	...	..
8.	Oxygen	36.02	..	35.82	..	36.290	...	54.70	..	10.10	..	25.87	...	...	..	53.16	..
9.	Fluorine	...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	..
10.		...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	..
11.	Sodium	...	0.59	...	0.70	..	0.645	...	0.62	...	0.17	..	0.30	...	..	...	0.62
12.	Magnesium	13.54	..	13.80	..	13.073	...	13.52	..	3.80	..	6.41	..	...	..	13.15	..
13.	Aluminium	...	1.39	...	1.45	..	1.527	...	1.25	...	0.39	..	0.59	...	..	...	1.21
14.	Silicion	18.41	..	18.18	..	18.154	...	15.79	..	5.20	..	7.53	...	...	..	15.35	..
15.	Phosphorus	...	0.06	...	0.11	..	0.113	...	0.05	...	0.14	..	0.18	...	0.17	...	0.06
16.	Sulfur	1.98	..	1.84	..	1.80	...	1.51	..	0.49	..	0.63	...	0.04	..	1.46	..
17.	Chlorine	...	..	...	..	..	0.080	...	..	...	..	..	...	...	..	...	..
18.		...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	..
19.	Potassium	...	0.17	...	0.27	..	0.174	...	0.11	...	0.04	..	0.04	...	..	...	0.11
20.	Calcium	1.65	..	1.26	..	1.730	...	1.01	..	0.046	..	0.47	...	...	..	0.97	..
21.		...	..	...	..	..	...	...	..	...	..	..	...	...	..	...	..
22.	Titanium	0.01	..	...	..	0.108	...	0.005	..	0.01	..	0.005	...	...	..	0.005	..
23.	Vanadium	...	..	...	..	..	Trace	...	..	...	..	..	...	...	..	...	..
24.	Chromium	0.28	..	0.58	..	0.321	...	0.13	..	0.09	..	0.07	...	0.01	..	0.13	..
25.	Manganese	...	0.14	...	0.36	..	0.224	...	0.06	...	0.03	..	...	...	..	...	0.06
26.	Iron	24.32	..	24.32	..	23.313	...	10.57	..	72.09	..	52.93	...	90.64	..	12.79	..
27.	Cobalt	...	0.05	...	0.05	..	0.017	...	0.02	...	0.44	..	0.31	...	0.59	...	0.04
28.	Nickel	1.31	..	1.26	..	1.527	...	0.54	..	6.50	..	4.52	...	8.50	..	0.76	..
29.	Copper	...	0.01	...	0.01	..	0.014	...	0.005	...	0.01	..	0.005	...	0.02	0.005	..
	Total	97.59	2.41	97.06	2.94	97.022	2.978	97.89	2.11	98.78	1.22	98.575	1.425	99.22	0.78	97.985	2.105
		100%		100%		100%		100%		100%		100%		100%		100%	

* 40, zirconium, none; 50, tin, none; 56, barium, none; elements 44, ruthenium; 46, palladium; 77, iridium; and 78, platinum, were found in stone meteorites, while 30, zinc; 33, arsenic; 51, antimony; 50, tin; 79, gold; 74, tungsten; and 92, uranium, were not found in the investigations reported by Merrill.

† It has been found by Farrington that the known falls of meteorites are in the ratio of 350 stone meteorites to 10 of iron.

The abundance relations in meteorites are exhibited graphically in Fig. 2, which gives the mean atomic percentages of the elements present in 350 stone and 10 iron meteorites, which is said to be the ratio of the known falls of these two classes.

It will be noted that in every case *the even-numbered elements are more abundant than the adjacent odd-numbered elements.* The rare gases of the atmosphere have been purposely omitted from the figure, since their physical and chemical properties are such that they could not be held by such small bodies as the meteorites, and the purpose of the diagram is to illustrate the general abundance relations of elements as nearly as is possible with the present limitations of knowledge. Table VI gives the average analyses of different types of meteorites as collected by different workers, and shows plainly that the predominance of the elements of even atomic number is not due to any selection of data. Even though the difference in the quantitative composition between the iron and the stone meteorites is very great, the atomic percentage of the elements of even atomic number is about 99 for the former and 98 for the latter.

15. THE PREDOMINANCE OF ELEMENTS OF EVEN ATOMIC NUMBER AS ILLUSTRATED BY THE COMPOSITION OF THE EARTH'S CRUST.

Since it has been shown that the elements of even atomic number are 70 times as abundant in the meteorites as those of odd atomic number, it should be of interest to see if the relations on the surface of the earth are at all similar. It should be remembered, however, that the crust of the earth is much more local in its character, and cannot therefore be expected to give such good evidence as that presented by the meteorites. It is found, however, that the elements of even number again show their predominance, since of the five most abundant elements, four have even atomic numbers, while of the first nine, six are even numbered, according to Clark's average for the composition of the lithosphere, as presented in Table VII.

The six even-numbered elements make up 85.74 per cent. of the lithosphere, while the three odd-numbered elements amount to only 12.77 per cent.

Table VIII gives another set of data for all of the elements as recalculated from a recent estimate made by Clarke and Washington.

The latter table shows that in the twenty top miles of the

earth's crust the atoms of elements of even atomic number are about nine times as numerous as those of odd atomic number.

Since the data presented for the composition of the lithosphere suffer from the disadvantage for the present purpose, that the surface of the earth has been subjected to extensive processes of differentiation, it would be of extreme value if evidence could be obtained in regard to elements which have not been thus affected.

TABLE VII.

Abundance (percentage by weight) of the Elements in the Lithosphere, Illustrating the Predominance of Elements of Even Atomic Number.

Atomic Number.	Element.	Even	Odd.
8	Oxygen	47.33	..
14	Silicon	27.74	..
13	Aluminium	...	7.85
26	Iron	4.50	..
20	Calcium	3.47	..
11	Sodium	...	2.46
19	Potassium	...	2.46
12	Magnesium	2.24	..
22	Titanium	0.46	..
		85.74	12.77

While this cannot be done, it would seem that elements which are very much alike both chemically and physically should be affected more nearly to the same extent than those which differ widely. Now the rare earths are so similar that they are separated in the laboratory only with great difficulty, so the writer first made an estimate of the relative abundance of these elements, and then secured estimates made independently by two noted authorities, Profs. C. James and C. W. Balke. It is of interest that these three estimates were all in agreement. They are given in Table IX, in which c indicates common in comparison with the adjacent elements and r represents rare; ccc represents a relatively very common element, etc. The comparison is only a rough one, but it indicates that the even-numbered rare earths are much more abundant than the adjacent ones which are odd.

The above results may be summarized in the statement that *in the formation of the elements much more material has gone into the elements of even atomic number than into those which are odd.*

16. THE UNKNOWN ELEMENTS.

Of the ninety-two elements within the limits of our present system, all but five have been discovered. It is of interest to note that all five *of the unknown elements have odd atomic numbers.*

TABLE VIII.

*Abundance of the Elements in the Crust of the Earth.**

(Atomic percentage for a twenty-mile crust.)

Order.	Element.	Atomic No.	Hydrogen.	Light Elements. Even	Light Elements. Odd	Heavy Elements. Even	Heavy Elements. Odd
1.	Oxygen	8		57.44			
2.	Silicon	14		18.23			
3.	Hydrogen	1	9.48				
4.	Aluminium	13			5.55		
5.	Sodium	11			2.27		
6.	Iron	26		1.68			
7.	Calcium	20		1.68			
8.	Magnesium	14		1.59			
9.	Potassium	19			1.223		
10.	Titanium	22		0.273			
11.	Carbon	6		0.152			
12.	Phosphorus	15			0.093		
13.	Chlorine	17			0.088		
14.	Sulfur	16		0.052			
15.	Manganese	25			0.041		
16.	Fluorine	9			0.030		
17.	Chromium	24		0.024			
18.	Nitrogen	7			0.022		
19.	Vanadium	23			0.015		
20.	Lithium	3			0.014		
21.	Zirconium	40				0.012	
22.	Barium	56				0.011	
23.	Nickel	28		0.010			
24.	Strontium	38				0.007	
25.	Ce-Yt					(0.0037)†	
26.	Copper	29					0.0033
27.	Glucinium	4		0.0019			
28.	Boron	5			0.0017		
29.	Zinc	30				0.0012	
30.	Cobalt	27			0.0010		
31.	Lead	82				0.0002	
	Total		9.48	81.1329	9.3487	0.0314 (0.0037)†	0.0033

100.00

0.000,0x	0.000,00x	0.000,000,x	0.000,000,0x	0.000,000,00x
Rhubidium	Cadmium	Bismuth	Platinum	Thallium
Arsenic	Mercury	Tungsten	Tellurium	0.000,000,000,x
Molybdenum	Iodine	Thorium	Gold	Indium
Tin	Caesium	Cb-Ta		Gallium
Bromine	Antimony	Uranium		0.000,000,000,0x
Scandium		Silver		Germanium
		Selenium		0.000,000,000,000,x
				Radium

* Recalculated from a recent estimate by Clarke and Washington.

†In the analyses for these elements those of odd and those of even atomic number are reported together.

17. THE GREATER STABILITY OF RADIOACTIVE ELEMENTS OF EVEN NUMBER.

Among the radioactive elements it will be seen too that if the most stable isotope of each element is considered, then in each case the odd-numbered element has either a shorter period than the adjacent even-numbered elements, or else is entirely unknown. This is shown by Table X.

18. CLASSIFICATION INTO LIGHT ELEMENTS (ATOMIC NUMBERS 1 TO 27) AND HEAVY ELEMENTS (ATOMIC NUMBERS 28 TO 92).

It has been seen that an important natural classification of the elements with respect to their nuclear characteristics is into those of even and those of odd atomic number. A second important natural classification, introduced in 1915,[22] is into light elements

TABLE IX.

*The Predominance of Even-numbered Elements Among the Rare Earths.**

Atomic Number.	Abundance.	Element.	Atomic Number.	Abundance.	Element.
55	c	Caesium	63	rr	Europium
56	ccc	Barium	64	r	Gadolinium
57	c	Lanthanum	65	rrr	Terbium
58	cc	Cerium	66	r	Dysprosium
59	r	Praseodymium	67	rrr	Holmium
60	c	Neodymium	68	r	Erbium
61	rrr	Unknown	69	rr	Thulium
62	c	Samarium			

*Calcium and barium are also included in the table.

up to atomic number 27, and heavy elements between atomic numbers 28 and 92. Of the latter elements 81 to 92 may be classed as specifically radioactive.

The classification was first made apparent by the mean atomic weights. It has been found that for the complex atoms of atomic numbers 2 to 27 the atomic weights are very close to whole numbers, with the exception of neon, magnesium, and chlorine (see Table II), and the exceptions were explained as due to the existence of considerable percentages of isotopes in these three elements.

It is very remarkable that while the atomic weights of the elements of numbers 19 to 27 are all very close to whole numbers, this approximation to whole numbers stops abruptly at this point, and from atomic number 28 to atomic number 80 the chemical atomic weights are practically as far from whole numbers as they should be from the standpoint of the laws of chance. It is also remarkable that for the heaviest or radioactive elements the mean atomic weights are again very close to whole numbers. It was pointed out by the writer seven years ago that the explanation of the above facts is that with the exception of neon, magnesium, and chlorine, isotopes do not occur in high percentages (in general not

[22] Harkins and Wilson: *J. Am. Chem. Soc.*, 37, 1386–96 (1915); Harkins: *Phys. Rev.*, 15, 79–94 (1920).

over 10 per cent. as a maximum) among the light elements, but beginning with nickel the number of isotopes and the distribution of the percentages of occurrence must increase. *Thus the region between atomic numbers 28 and 82 is one of many stable isotopes.* The general theory of the writer points out, however, that it is only among the even-numbered elements that the number of isotopes should increase very markedly in this region, since the number of

TABLE X.

Half Life of the Most Stable Isotope of the Radioactive Elements.

Atomic number.	Element.	One-half period of most stable isotope.	
		Even.	Odd.
92	Uranium	5 billion years	
91	Uranium X_2		1.15 min.
90	Thorium	18 billion years	
89	Actinium		Period unknown, but almost certainly less than radium
88	Radium	1730 years	
87			Element undiscovered
86	Niton	3.85 days	
85			Element undiscovered
84	Polonium	136 days	

isotopes per element should in general remain much lower when the atomic number is odd.

Table XI shows that while the deviation of the atomic weights from a whole number is only 0.01 unit between atomic numbers 2 and 9, is 0.046 between 11 and 16, and only 0.07 between numbers 18 and 27, it rises to 0.247 from 28 to 37, and is also 0.247 between numbers 38 and 48. It should be noted that between atomic numbers 28 and 48 the average deviation from a whole number is almost exactly what it should be from the laws of chance. Thus an altogether random distribution of numbers would show a deviation of 0.250 from a whole number while each ten elements in this range show that the deviation is actually 0.247, which is almost the identical value for an entirely random distribution. The remarkable feature of the table is that it also shows that the large deviation from a whole number begins *suddenly* at nickel with a value of 0.32, is 0.43 for copper, 0.37 for zinc, etc.

Between atomic numbers 49 and 58 the deviation from a whole number becomes slightly smaller, and is thus a little less

than is indicated by chance alone, the value being 0.229. Between atomic numbers 73 and 80 there is a further slight decrease to 0.214. However, the second remarkable feature exhibited is that between atomic numbers 81 and 92 the mean deviation falls to 0.102, or to much less than is indicated by a chance formation. This is due to the fact that while there are many isotopes of the elements 81 to 92, most of these isotopes are unstable, and in radium, thorium, and uranium, one isotope is in each case so much more stable than the others that the atomic weight of the element is practically that of the single most stable isotope.

19. THE ALPHA PARTICLE AS THE PRINCIPAL CONSTITUENT OF ALL ATOM NUCLEI, AND THE INDICATION THAT THERE ARE MANY ISOTOPES OF ELEMENTS OF EVEN ATOMIC NUMBER HIGHER THAN 28.

Table XII gives very definite evidence for considering that the alpha particle is the principal constituent of atom nuclei, and at the same time shows plainly that exactly at atomic number 28 where the atomic weights, as they increase, suddenly cease to be divisible by unity, they also cease to be divisible by 4, when the elements of even atomic number only are considered. This gives an additional indication that isotopes become numerous above atomic number 28.

While it is thus apparent that if the chemical atomic weights alone are considered, both the whole number rule, and the divisibility by 4 of the atomic weights of elements of even atomic number, seem to break down above atomic number 28, it is evident that this apparent invalidity of these rules is entirely illusive, since it is just among the heaviest or radioactive elements, that we have the direct experimental evidence that the elements change from one to another by the emission of alpha particles whose atomic weight is 4.00. Also, as noted in a previous paragraph, the whole number relation for the mean atomic weights appears to hold for the radioactive elements. Table XIII shows that the atomic weights of the radioactive elements of the uranium and thorium series are all even numbers.

It also exhibits the interesting relation that the atomic weight of helium, as derived by calculation from the chemical atomic weights of the radioactive elements, are as accurate, and also practically identical with those obtained from direct determinations.

TABLE XI.

Deviations of the Atomic Weights from Whole Numbers, Showing that for the Heavier Elements there is no Tendency for these Weights to Approximate Whole Numbers, while the Atomic Weights of the Elements below No. 28 are Extremely Close to Whole Numbers.

Few Isotopes.				Many Isotopes for Elements of Even Atomic Number.									
At. No.	Element.	At. Wt.	Diff. from Whole No.	At. No.	Element.	At. Wt.	Diff. from Whole No.	Probable Error in At. Wt.	At. No.	Element.	At. Wt.	Diff. from Whole No.	Probable Error in At. Wt.
2	He	4.00	0.00	28	Ni	58.68	0.32	0.02	49	In	114.8	0.2	0.5
3	Li	6.94	0.06	29	Cu	63.57	0.43	0.05	50	Sn	118.70	0.30	0.2
4	Be	9.017	0.017	30	Zn	65.37	0.37	0.05	51	Sb	120.2	0.2	0.3
5	B	10.9	0.10	31	Ga	70.1	0.10	0.5	52	Te	127.5	0.5	0.2
6	C	12.0025	0.0025	32	Ge	72.5	0.50	0.5	53	I	126.92	0.08	0.03
7	N	14.008	0.008	33	As	74.96	0.04	0.05	54	Xe	130.2	0.2	0.2
9	F	19.00	0.00	34	Se	79.2	0.20	0.1	55	Cs	132.81	0.19	0.05
				35	Br	79.923	0.08	0.1	56	Ba	137.37	0.37	0.03
Av. variation			0.039	36	Kr	82.92	0.08	0.1	57	La	139.0	0.0	0.3
				37	Rb	85.45	0.45	0.05	58	Ce	140.25	0.25	0.1
11	Na	23.00	0.00	Av. variation			0.247		Av. variation			0.229	
13	Al	26.97	0.03										
15	P	31.04	0.04						73	Ta	181.5	0.5	1.0
16	S	32.07	0.07						74	W	184.0	0.0	0.5
									76	Os	190.9	0.1	0.4
Av. variation			0.035						77	Ir	193.1	0.1	0.2
				38	Sr	87.63	0.37	0.03	78	Pt	195.2	0.2	0.1
18	Ar	39.9	0.10	39	Y	89.0	0.0	0.2	79	Au	197.2	0.2	0.1
19	K	39.10	0.10	40	Zr	90.6	0.4	0.2	80	Hg	200.6	0.4	0.4
20	Ca	40.07	0.07	41	Cb	93.5	0.5	...	Av. variation			0.214	
22	Ti	48.10	0.10	42	Mo	96.0	0.0	0.1					
23	V	51.00	0.00	44	Ru	101.7	0.3	0.1	81	Tl	204.0	0.0	0.2
24	Cr	52.00	0.00	45	Rh	102.9	0.1	0.05	82	Pb	207.20	0.20	0.1
25	Mn	54.93	0.07	46	Pd	106.7	0.3	0.1	88	Ra	226.0	0.0	0.1
26	Fe	55.84	0.16	47	Ag	107.88	0.12	0.02	90	Th	232.15	0.15	0.1
27	Co	58.97	0.03	48	Cd	112.4	0.4	0.03	92	U	238.16	0.16	0.1
Av. variation			0.070	Av. variation			0.247		Av. variation			0.102	

Note.—One of the remarkable features of this table is that the average deviation from a whole number is very low for both the light and the heaviest atoms, but is large between atomic numbers 28 and 80.

20. THE LIGHT ELEMENTS (ESPECIALLY THOSE WHOSE CHEMICAL ATOMIC WEIGHTS ARE DIVISIBLE BY 4) ARE ABUNDANT, THE HEAVY ELEMENTS ARE RARE.

The classification of elements into light and heavy is also of value in connection with the abundance of the elements. Thus

about 99.9 per cent. of all known material consists of the elements of atomic number 1 to 28. In spite of the fact that according to the classification adopted in this paper there are twice as many heavy *elements* as of light elements, and probably four or five times as many heavy atomic *species* than of light species, only

TABLE XII.

Illustrates the Helium Structure of the Nucelei of Atoms.

Atomic Number.	Atomic Weight Divided by 4.	Deviation from a Whole Number.
2	1.00	0.00
6	3.00	0.00
8	4.00	0.00
10	5.04	0.04
12	6.08	+0.08
14	7.07	+0.07
16	8.01_8	$+0.01_8$
18	9.97	−0.03
20	10.02	+0.02
22	12.02_8	$+0.02_8$
24	13.00	0.00
26	13.96	−0.04
Average deviation from a whole number up to this point is the extremely small amount of 0.026.		
28	14.50	+0.50
30	16.34	+0.34
32	12.18_8	$+0.12_8$
34	19.80	−0.20
36	20.73	−0.27
38	21.91	−0.09
40	22.65	−0.35
42	24.00	0.00
44	25.42_8	$+0.42_8$
46	26.67_8	-0.32_8

Average deviation from a whole number for 10 elements beginning with element 28 is equal to 0.262, or almost what it should be by chance (0.250). *Notice that the break occurs exactly at element 28 (Ni), which is exactly the same element at which the atomic weights themselves cease to be close to whole numbers.*

about 0.10 per cent. of the material belongs to the heavy elements. Thus the ratio of abundance is of the order of one thousand to one in favor of the less numerous light elements.

While these facts have been known for a long period, as has been pointed out by Clarke, it had sometimes been considered that this was due to the sinking of the heavy elements to the centre of the earth, but has usually been left unexplained. The writer in 1917 presented evidence which seems to prove that *the explanation of these facts lies in the method by which the atoms were built, and by their stability relations.*

Table XIV gives the proportion by *weight* in which the heavy and light elements exist in different materials.

It is apparent that if the percentages were to be given in terms

of the number of atoms, the abundance of the heavy elements would be very much less than that indicated in the table.

Thus *so far as the abundance of the elements is concerned the system seems to almost play out beyond atomic number 28, which is the last of the abundant elements.*

TABLE XIII.

Atomic Weights of Radioactive Atoms.

Atom.	Atomic Weight.	Deviation from a Whole Number.	Atomic Weight.
Uranium	238.175	+0.175	59×4.0030+2.00
Thorium	232.12	+0.12	58×4.0023
Radium	225.97	−0.03	56×3.9983+2.00
Radio-lead (Ra G)	206.07	+0.07	51×4.0014+2.00

Table VIII shows that in the earth's crust *the number of atoms per light element is 5000 times as large as the number per heavy element.* Since there are many more isotopes of the heavy than of the light elements, the number of atoms per atomic species is extremely small above atomic number 28. It seems probable that on the average a light atomic species consists of 20,000 times as many atoms as a heavy atomic species. Since hydrogen and helium are the fundamental building blocks of the system, their abundance should not be and have not been included in such considerations as those presented above.

TABLE XIV.

Proportion in Various Materials of the Elements of Low Atomic Numbers.

	Percentage of elements with atomic numbers.	
	1-29	30-92
Meteorites as a whole	99.99	0.01
Stone meteorites	99.98	0.02
Iron meteorites	100.00	0.0
Igneous rocks	99.85	0.15
Shale	99.95	0.05
Sandstone	99.95	0.05
Lithosphere	99.85	0.15

21. PRIMARY AND SECONDARY FACTORS WHICH DETERMINE THE ABUNDANCE OF THE ELEMENTS.

It is evident from the preceding discussion that there is a direct relation between the abundance of the elements and the

atomic number, and that there is no very marked relation to the periodic system of Mendelejeff. This indicates that the abundance of the elements is determined in a primary sense by the stability relations of the complex atoms themselves, and also by the stability of the electron-proton groups, such as the alpha particle, from which they are built. However, it is obvious, *even if in the formation of the elements there is no relationship to the ordinary periodic system, that in all of the differentiative processes which occur after the original formation, the chemical and physical properties would play their part, so that if any special material is taken for consideration, relationships to that system would appear more and more as the process of differentiation takes place.*

The fact that in the meteorites the elements of even atomic number are in all cases more abundant than the adjacent elements of odd number, seems to indicate that in such bodies the process of differentiation has not proceeded to such an extent as to cause the chemical and physical properties to have an influence sufficient to obscure in any marked degree the most general of the abundance relations due to nuclear stability, but it does not show that there has been an entire absence of differentiation. The composition of the earth's surface, as compared with that of the meteorites, shows a less rigid, but very marked adherence to the odd and even system, but certain groups of elements related in chemical and physical properties, are relatively more abundant. Thus the alkali metals, sodium and potassium, the halogens, and aluminium are present in much larger quantities. In the meteorites calcium is much less abundant than magnesium, while on earth both elements are of the same order of plentifulness.

22. THE GREAT STABILITY OF THE ALPHA PARTICLE DEDUCED FROM THE SPECIAL RELATIVITY THEORY.

That the alpha particle has a high order of stability seems to be shown by the fact that it holds together when emitted from radioactive nuclei at speeds as high as twenty thousand miles per second. Considerable interest has recently been manifested in the fact that the special theory of relativity also indicates its extreme stability, as was first shown by Harkins and Wilson[23] in 1915.

According to this theory one gram of mass is equivalent to 9×10^{20} (the square of the velocity of light) ergs of energy, or

$$E = mc^2$$

[23] Harkins and Wilson: *Phil. Mag.*, 30, 731–3 (1915).

where E represents energy, m mass, and c the velocity of light. The change of mass involved in the formation of one gram atom of helium (4.000 grams) from 4 gram atoms of hydrogen (4×1.0078 or 4.0312 grams) is 0.0312 grams, so the energy change in the process should be

$$\Delta E = -0.0312 \times 9 \times 10^{20} = -2.808 \times 10^{19} \text{ ergs}$$
$$= -6.708 \times 10^{11} \text{ calories.}$$

Thus 6.708×10^{11} calories of energy are given off in the formation of 1 gram atom of helium, and this represents the free energy decrease. Now the free energy decrease in the formation of one mol of water from hydrogen and oxygen at atmospheric pressure is 57,000 calories, which is usually considered to be a large decrease. The magnitude of the change in the formation of one gram atom of helium is thus more than ten million times that in the formation of a mol of water.

The energy produced in this way would be of great importance if the reaction could be made to proceed, since one pound of hydrogen would give, if converted into helium, as much heat as 10,000 tons of coal.

This great amount of energy would be given off in the reaction

$$4H = He,$$

but, since the two outer electrons are, even in the helium atom, attached very loosely in comparison with those in the nucleus, it is evident that the heat is practically all given off in the reaction

$$4p + 2e = p_4e_2,$$

that is in the formation of the alpha particle from four protons and two electrons.

While nothing is known of the conditions under which this reaction takes place, it is possible that it occurs at high temperatures, or at high pressures, or when both the pressure and the temperature are high. *The occurrence of the reaction in the stars, or the sun, would be a possible source of the heat of these bodies,* which seems to be in excess of any amount which could be obtained by purely physical or chemical changes.

At first thought it seems remarkable that a reaction which would liberate such an extremely large amount of energy, does not occur at a detectable rate in ordinary hydrogen gas at moderate temperatures. However, this is only a more marked example of

what is found in the union of hydrogen with oxygen at ordinary temperatures. While the free energy of this latter reaction is high, it does not occur at a measurable rate. In the formation of the alpha particle six electrons are involved, and it is probable that these electrons, four positive and two negative, must arrange themselves in a definite configuration before an alpha particle is formed. Thus the chance that this particular arrangement will occur is very slight, so that the reaction is a very slow one, at least under ordinary conditions.

23. A MODEL FOR THE ALPHA PARTICLE.

The most important condition which must be met by any successful model of the alpha particle is that it must give an explanation of the packing effect, amounting to 0.77 per cent. decrease when the four protons and two electrons unite. A decrease in mass indicates that in the alpha particle the positive electrons must be very close to the negative electrons, in order that the mass of the former shall be decreased by about the above percentage. The mass of the negative electrons is so small already before the combination, that any decrease in their mass cannot contribute in any large way to the total effect. It has already been mentioned that if the inverse square law were to hold at such minute distances, the charges on the positive and negative electrons would need to be displaced or else the positive electrons would need to be imbedded in the negative electrons, to give a loss of mass of such a considerable magnitude. However, it seems probable that the inverse square law does not hold, and that the law of force changes rapidly, the power increasing, as the electrons approach each other very closely.

The greatest difficulty in constructing such a model is that we are ignorant of the distribution of electricity in electrons, their form is unknown, and the relative sizes of the negative and positive electrons are undetermined. If the Lorentz form of electron, and the inverse square law in the electron itself, are assumed, the positive electron should have a diameter only $1/1835$ that of the negative, since the mass of the former is 1835 times larger (Equation 2, Section 7). Using this general result as a basis, the model of the alpha particle adopted by the writer [24] assumes that the positive electron is smaller than the negative

[24] *Phys. Rev.*, **15**, 82, February (1920). (Paper presented in May, 1919.)

electron, but not necessarily as much smaller as equation 2 indicates.

While the positive electrons must be very close to the negative to give the packing effect, it is evident that the positive electrons themselves cannot be close to each other, since any such proximity would mean a considerable *increase* of mass, while the packing effect is a decrease. Fortunately, with large electrons and small protons it is possible to construct a model in which the protons are relatively far apart, but with the electrons and protons very close together. Such a model is presented in Fig. 3.

24. THE MASS AND ENERGY EVOLVED IN THE DISINTEGRATION OF RADIOACTIVE SUBSTANCES.

In the last section the energy evolved in the formation of one gram atom of helium was calculated from the mass change involved, in the present section the converse problem will be treated, the calculation of the change of mass from a change in energy for each radioactive series, the end product in each case being lead. The total energy change per gram atom of lead formed is about 0.05 gram, or about 66 per cent. greater than that in the formation of one gram atom of helium, but it should be considered that the total mass involved is more than 50 times as large in the case of the radioactive substances. Also seven or eight alpha changes occur in each radioactive series, and it is the total mass change for all of these which is given above. The first calculation of this nature was made by Swinne [25] in 1913. The calculations given here were made two years later by W. D. Turner and the writer from data [26] published in 1914.

The amount of energy given off in an alpha disintegration may be calculated by the method given below, and this may be checked in some cases by comparison with the results obtained in direct calorimetric measurements. The energy involved in beta disintegrations is relatively so small that it may be neglected. The initial velocity (v) of an alpha particle may be calculated from the range (R) by the equation of Geiger [27]

$$v^3 = aR \qquad (1)$$

where a is a constant.

[25] Swinne: *Physik. Z.*, **14**, 145 (1913).
[26] *Le Radium*, 1914.
[27] Geiger: *Proc. Roy. Soc.* (A), **83**, 505 (1910).

The value of the constant a has been found to be 1.33×10^{28} by measurements on radium C.

Now

$$E_t = \tfrac{1}{2} mv^2 \qquad (2)$$

so from (1)

$$E_t = \tfrac{1}{2} m(aR)^{2/3} \qquad (3)$$

in which m, the mass of the alpha particle, is 6.6×10^{-24} grams.

To this must be added the energy of recoil of the disintegrating atom, which may be calculated on the basis that its momentum is equal to that of the alpha particle.

$$MV = mv \quad \text{so} \quad \tfrac{1}{2} MV^2 = \frac{m}{M} \cdot \tfrac{1}{2} mv^2 = \frac{m}{M} \cdot E' \qquad (4)$$

Therefore the total emission of energy per alpha particle is

$$E' = \left(1 + \frac{m}{M}\right) E_t \qquad (5)$$

$$E' = \left(1 + \frac{m}{M}\right) \tfrac{1}{2} m (aR)^{2/3} \qquad (6)$$

The number of alpha particles given off in the disintegration of a gram atom of a radioactive substance by one alpha change, is 6.06×10^{23}, so the energy per gram atom of helium emitted is

$$E = 6.061 \times 0^{23} \; E' = 6.06 \times 10^{23} \left(1 + \frac{4.00}{P}\right) \tfrac{1}{2} \frac{4.00}{6.06 \times 10^{23}} (aR)^{2/3}$$

$$= 2.42 \times 10^{18} \left(1 + \frac{4}{P}\right) R^{2/3} . \qquad (7)$$

The energy evolved per gram atom of substance per second (E_0) is the product of the energy per alpha particle times the number (N) of alpha particles given off per second, plus the correction for the recoil atom:

$$E_0 = N\left(1 + \frac{m}{M}\right) E_t = NE' \qquad (8)$$

With E_0 known, the total energy emitted ΔE during the entire transformation may be found from the radioactive constant (λ) by means of the equation:

$$\Delta E = E_0/\lambda \qquad (9)$$

From the value of the energy the equivalent in mass may be calculated by the equation of Einstein.

$$M = \frac{\Delta E}{9 \times 10^{20}} \qquad (10)$$

[25] Rutherford: "Radioactive Substances," p. 582.

25. EXPERIMENTAL TESTS OF THE SPECIAL RELATIVITY THEORY.

Since the loss of mass between uranium and lead amounts, according to these calculations from the relativity theory, to about one-twentieth of a gram, it is obvious that this part of the theory is susceptible to experimental test, since if atomic weight determinations could be made on both uranium and radium G, or on thorium and thorium-lead, with an error of less than one one-hundredth unit, the difference between the two extreme atomic weights should be equal to 32.05 in the former, and 24.04 in the latter, of the two cases. Since no atomic weights have as yet been determined in the actinium series, checking up the use of the calculated difference in this series with that determined experimentally does not look so hopeful. Since most of the loss of mass in the radium series occurs between radium and radium G (lead

TABLE XV.

The Change of Mass During the Disintegration of Radioactive Substances.

Atomic Species	Atomic Weight	Range R	Change of Energy in Ergs x 10^{-18}	Change of Mass.	
Uranium Series					
Uranium I	238	2.37	4.27	0.00475	
Uranium II	234	2.75	4.83	0.00536	
Ionium	230	2.85	4.94	0.00549	
Radium	226	3.13	5.86	0.00585	
Emanation	222	3.94	6.14	0.00682	
Ra A	218	4.50	6.71	0.00746	
Ra C′	214	6.57	8.80	0.00977	
Ra F	210	3.58	5.77	0.00641	
Total loss of mass: uranium to lead					0.052 grams
Thorium Series					
Thorium	232	2.58	4.63	0.00514	
Radiothorium	228	3.67	5.86	0.00651	
Thorium X	224	4.08	6.28	0.00698	
Th emanation	220	4.74	6.94	0.00772	
Thorium A	216	5.40	7.58	0.00842	
Thorium C′	212	8.16	9.98	0.01110	
Total loss of mass: thorium to lead					0.046 grams
Thorium C	212	4.55	6.76	0.00752	
Total loss of mass: thorium to lead					0.042 grams
Actinium Series					
Protoactinium	230?	3.5	4.48	0.00500	
Radioactinium	226	4.36	6.57	0.00730	
Actinium X	222	4.17	6.38	0.00709	
Ac emanation	218	5.40	7.58	0.00842	
Actinium A	214	6.16	8.28	0.00920	
Actinium C	210	5.12	7.32	0.00814	
Total: protoactinium to lead					0.045 grams
Total loss of mass: uranium to lead (provided series comes from U_{II}) about					0.054 grams

206), it would be possible to use the atomic weights of these two elements instead of those of uranium and radium G.

A more direct, but less hopeful method experimentally, on account of the too costly initial investment and the scarcity of materials, would be to seal up in a glass and then in a metal tube, a sample of radiothorium or mesothorium, or some other very radioactive substance, and to detect the loss of mass by weighing the tube with extreme care at long intervals of time. In order that the time might not be too long, the amount of mesothorium taken should be considerable. The tube would need to be provided with a sealed-in conducting wire in order to prevent the accumulation of a charge, but the preservation of a gas-tight seal could be insured by a careful sealing of the platinum outside tube. If alpha particles and helium gas were prevented from escaping, a loss of mass of the tube and its contents would be a qualitative test of the theory of relativity. By carefully determining the amount of radioactive material in the beginning, the test could be made quantitative. The difficulty of the experiment lies in the fact that with ten grams of radium it would take about 1800 years to get a loss of mass of one milligram. While the same amount of radiothorium would give this loss of mass in three years, radiothorium is very much more rare, though cheaper in proportion to its activity, than radium.

The tests of the special relativity theory here outlined involve the assumption that the energy involved comes entirely from the atoms, and that it is not supplied to the atoms during the experiment in the form of some penetrating radiation or otherwise.

(*To be continued.*)

On a New Type of Transformation in Iron. G. BORELIUS and F. GUNNESON, University of Lund. (*Ann. d. Physik*, No. 3, 1922.) —We have alpha, beta and gamma rays and there was a time when there were N-rays too, though they have ceased to exist. X-rays are with us for all time, and now here are two papers to convince us that there are Z-transformations in iron. How are these transformations detected? By a study of the thermo-electric powers of the specimens under examination.

A piece of iron wire was heated in an electric furnace, then promptly cooled by dropping in water. After this its thermo-electric power at room temperature was measured. A similar piece was thereupon heated to a somewhat higher temperature, cooled and its power measured, and so on. When the temperatures are plotted as abscissas and the thermo-electric powers as

ordinates a series of waves manifest themselves. From a long series of observations it appears that the presence of certain appropriate substances in the iron augments the amplitude of the waves. Electrolytic iron, heated for hours in an atmosphere of illuminating gas, furnished waves of especially great amplitude; while the same kind of iron, melted in a vacuum to form an alloy containing 5 per cent. silicon, gave a smooth curve. Heating the specimen in gas, however, made the waves appear.

Not only are there waves, but they are rather regular waves, so regular in fact, that if we agree to recognize each of them as indicating a modification of the iron, it may be said that the middle temperature of each transformation interval is computed in absolute degrees by multiplying the ordinal number of the transformation by 97. If we take the tenth transformation, we thus get for its temperature 970° abs., which is just about the perlite or Curie point. Perrier and Wolfers at the general meeting of the French Physical Society, January 21, 1921, presented a method of detecting transformations in substances, and state that there is an anomaly in iron at 1140°. If 273° be added to this to change to absolute degrees the sum is 1413, which is about midway between 14 and 15 times.

There had previously been reason to infer that strange things happen to iron in addition to the fully recognized and catalogued transformations. Roberts–Austen of the British Mint and A. Mueller noticed that electrolytic iron with a high content of hydrogen, upon heating, gives up the gas, not gradually, as one would expect, but only at certain temperatures. Moreover the density of a certain steel has been found to be a periodic function of the temperature of tempering. With a wider view Robin detected a connection between temperature and tensile strength, hardness and elasticity that pointed toward transformations. Certain magnetic relations tend to confirm this conclusion.

It has been mentioned that silicon, which forms a stable solid solution with iron, does not incite to transformation, while carbon does favor such changes. There is yet no definite experimental evidence to show in what the transformations consist, though the suggestion is made that we must look to the space lattice of the metal for the answer.

At the meeting of the Strasbourg Section of the French Physical Society, December 16, 1921, the president of the parent society, Paul Janet, presided. Langevin in his discussion of "The Dynamics of Relativity," said the following: "The theory of relativity is the only theory which takes into account all the facts of physics actually known and which from them makes possible the prediction of new facts. In particular in the domain of limited relativity, that is, in the absence of a gravitational field, it leads to a new system of dynamics where the mass of a body ceases to be a constant and varies not only with the velocity of the body, but also with its interior state, where, further, the conception of mass merges with that of internal energy.

G. F. S.

THE FIRE-FLY AS AN ILLUMINANT.*

BY

HERBERT E. IVES, Ph.D.

Member of the Institute.

INTRODUCTORY.

THE purpose of this paper is to review the results of a series of studies made some years ago on the physical properties of the light emitted by the fire-fly. As these studies appeared in several different scientific and technical journals, their essential unity of object has perhaps been somewhat obscured. Together they constitute practically the first, and even at this date the chief, definite *quantitative* data on the radiant emission of the fire-fly considered from the standpoint of the illuminating engineer; that is, covering such essential points as efficiency and intensity. More accurately determined figures for the fundamental constants of illumination are now available, so that in assembling and reviewing the original fire-fly data it has been possible to establish with greater exactness their significance in connection with practical light production. Some variations on the method of treating the subject in the original communications have also appeared desirable upon considering the matter as a whole, and have accordingly been introduced.

SIGNIFICANT CHARACTERISTICS OF AN ILLUMINANT.

The most important questions to be answered in studying an illuminant are three: *How much* light does it produce; how *efficiently* does it produce the light; what is the *quality* of the light? Let us consider each of these attributes briefly.

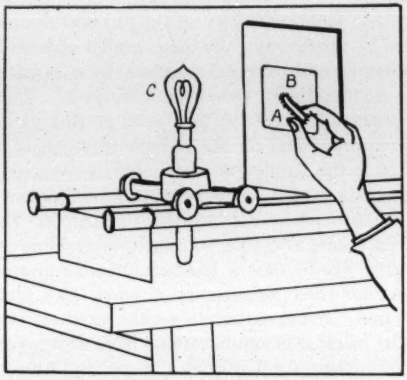
The *quantity* of light which could be got from an artificial source was undoubtedly the first problem of the first illuminating engineer. He cared nothing about efficiency in the physical sense; "hot light" was just as acceptable to him as "cold light" (often even more acceptable). There must be enough light to scare off wild animals, to illuminate the approaches to camp or cave, to make possible the performance of simple mechanical operations such as preparing weapons or implements for hunting. If his

* Communicated by the Author.

camp-fire, torch, or flaring wick floating in grease gave an adequate quantity of light it sufficed, irrespective of efficiency or color.

But the requirement as to quantity is not quite so simple as it may have appeared to primitive man. It might well have happened that a fire bright enough to see by would have been too hot to sit by. It might well have happened that a torch bright enough

FIG. 1.



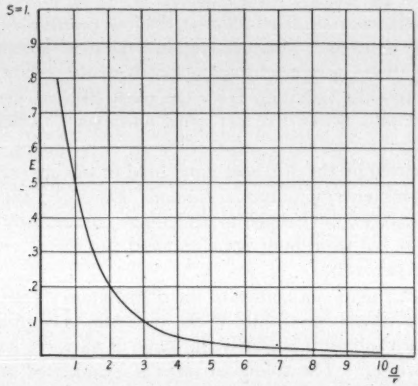
Method of measuring the light of the glowworm.

to light his way would have been too heavy to carry. It might well have happened that his sole light source at night would have been only bright enough, no matter how large it was made, to be seen, and not bright enough to see by, as is actually the case with certain phosphorescent glowing bacteria. It therefore becomes obvious that the *size* of the light source must be considered as well as its total emission. It is in fact with the relation of light emission to emitting area that the lighting engineer is concerned. The physical quantity of significance is the *specific luminous emission*, or luminous emission per unit area, measured in *lumens per square centimetre*. If this falls below a certain minimum the light source is unavailable for purposes of illumination. If it exceeds this minimum, but is low, the source will be available only where space is ample, and when portability is not essential. If the specific emission is high, it becomes possible to construct an illu-

minant, compact in size, whose luminous emission is susceptible of direction or diffusion. It is illuminants of this latter class that have played the greatest rôle in artificial lighting; their admirable flexibility does not, however, entirely close the field to light sources of low specific emission should those latter possess other claims to use, such as high efficiency.

Considering now *efficiency;* primitive man knew nothing of luminous efficiency in the physical sense; he was concerned with

FIG. 2.



Illumination due to circular disc of diffusely radiating material of specific luminous emission *S*, at various ratios of distance (*d*) to radius (*r*).

efficiency only from the standpoint of the cost of his materials, and until recent times the cost of the wood, tallow or oil used in fabricating the light source counted little against the boon of having any sort of useful light at night. This condition of affairs is indeed still largely true, but scientific study has revealed that the ordinary processes of light production are criminally inefficient when we measure the ratio of light yielded to energy put in. Any process in which a representative figure for efficiency is one per cent., as is the case in light production, is an anomaly and a challenge to present-day engineering.

The measurement of the efficiency of light production may logically be undertaken in two steps. The first step is to determine the efficiency with which the energy supplied is transformed into

radiant energy—*the radiational efficiency*. The second step is to determine the *radiant luminous efficiency;* that is, how efficient is this radiant energy as light—does it lie in the visible spectrum, and how advantageously is it placed in the visible spectrum? The product of these two efficiencies is called the *total luminous efficiency*. The radiational efficiency of a light source may run above 90 per cent., as it does in the case of a vacuum incandescent electric lamp. Flame-heated radiants such as a Welsbach mantle lose so much heat by convection that their radiational efficiency falls as low as 50 or even 25 per cent. It is, however, in the luminous efficiency of the radiation that all practical illuminants are so badly deficient. Measured against the most advantageously placed radiation—a monochromatic patch in the yellow-green of the spectrum—the radiation from the most efficient incandescent illuminants falls below five per cent. efficiency. Efficiencies of light production, properly expressible in percentages, are commonly obscured by the different units used in stating energy input and luminous energy output. *Lumens per watt,* the practical measure, may be transformed to percentage efficiency by using the relation that the maximum possible (100 per cent.) efficiency is 640 lumens per watt.

Quality of light is a matter of the distribution of the radiation through the visible spectrum. If the spectrum is continuous, and if the radiant intensity is nearly the same at all wave-lengths, the light is "white." The colors of objects illuminated are seen in their true (*i.e.,* their daylight) values; the light is pleasant. If the spectrum is continuous but much more intense toward the long wave (red) end, the light will appear yellow, but may still be agreeable in integral color; illuminated objects will be distorted from their daylight color values, although usually maintaining their same relative position on a color scale. This is the type of spectral energy distribution presented by the great majority of artificial illuminants, such as flames and glowing filaments. If the spectrum is discontinuous, so that only certain regions of the spectrum are present, the light may appear of any integral color, including white, depending on the relative intensities of the constituents; it may or may not be pleasant as an illuminant. Color values of illuminated objects will then be distorted in more or less peculiar ways, depending on the coincidence or lack of coincidence of the wave-lengths which are present in the light and reflected

by the object. If the spectrum of the light is so discontinuous as to be monochromatic, the deficiency of color-rendering capacity may be offset for certain purposes, by a useful property possessed in greater degree by monochromatic illumination than by continuous spectrum illumination of the same intensity; this is the property of rendering visible fine details. *Visual acuity* is considerably greater by monochromatic light, and is also notably higher for the middle (green) of the spectrum, than for the ends (red and blue).

We are now ready to consider in detail the fire-fly, as an illuminant, taking up in order its specific luminous emission, its efficiency, the quality of its light.

SPECIFIC LUMINOUS EMISSION OF THE FIRE-FLY.

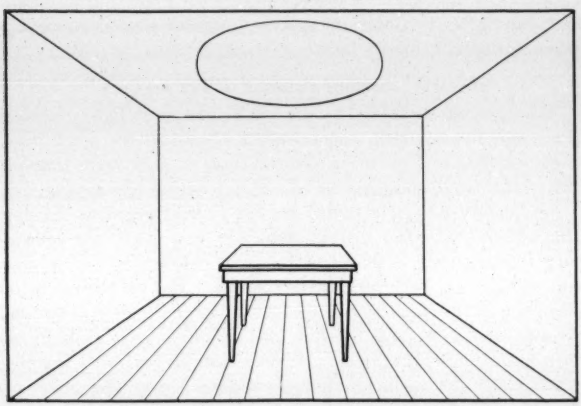
We must not be misled by the small amount of light given out by a single fire-fly flash, particularly the flash of the small insect of the eastern and northern United States. The large Jamaica variety has been estimated by W. H. Pickering [1] to give a flash of .004 candle-power, a figure arrived at by comparing its flash with stars of various magnitudes. At first sight the idea of using lighting units of this size for practical illumination appears wild enough to discourage further study. But as already noted we must take into account the area from which the light is emitted. For these large tropical fire-flies the luminous area is about one and a half square centimetres. If the luminous portion is assumed to be a plane, the specific luminous emission (πx candle-power per unit area) works out as

$$\frac{.004}{1.5} \times \pi = .0084 \text{ lumens per square centimetre.}$$

This is a figure which we could use if necessary. It is not entirely satisfactory, because of uncertainties due to comparing intermittent and steady lights. Furthermore, even should this specific luminous emission prove to have practical value, the fact that the light is only available in widely separated flashes might well make us pause before drawing conclusions as to the real efficiency of the process. Indeed, were the intermittent character of the fire-fly's light proved to be fundamental and inevitable, it would be questionable whether its further study would be worth while from our standpoint. Fortunately for the fate of the whole problem, and for the particular problem of measurement, the *larva* of the fire-fly

gives a continuous steady glow of very nearly, if not quite the same, quality as the flashing light, not so bright as the isolated flashes, although very probably of nearly the averaged value of these. This steady larval light is much more suitable for measurement, analysis, and ultimate copying, if that be possible or desirable, than the more spectacular performance of the adult creature. The rather exact measurements of specific luminous emission which are described below [2] were made on specimens of the larva

FIG. 3.



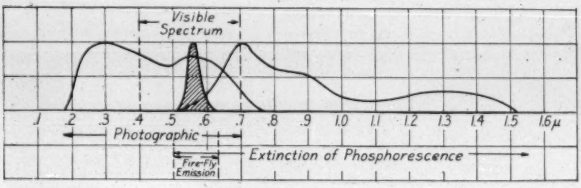
Illumination of room by diffusely radiating disc at ceiling.

of one of the Pennsylvania varieties of fire-fly, much smaller, although perhaps intrinsically just as bright (*i.e.*, as intense per unit emitting area) as the more famous West Indian varieties.

The method of measuring the luminous emission of the larva or glow worm is illustrated in Fig. 1. It was noticed that the light-giving portion of the glowworm, located on its abdomen, could be so turned as to be on the extreme edge of its profile. If then the worm was held in front of a large bright area, this luminous spot together with the background formed the two parts of a simple photometric field. In the diagram *A* is the glowworm, held between thumb and forefinger; *B* is a white diffusely reflecting surface illuminated by the standard lamp *C*, whose distance from *B* is adjustable (the glowworm was of course

shielded from the direct light of the lamp by screens not shown in the figure). The process of measurement consisted in varying the position of the standard lamp until the glowworm and the white surface appeared equally bright. Although there is a considerable difference in color between the standard (carbon incandescent lamp) and the glowworm, settings were made without difficulty. The result of the experiment gave as the mean value of the illumination of the white surface (calculated by the inverse square relation from the distance of the standard lamp) necessary

FIG. 4.



Regions of the spectrum covered by photography and extinction of phosphorescence.

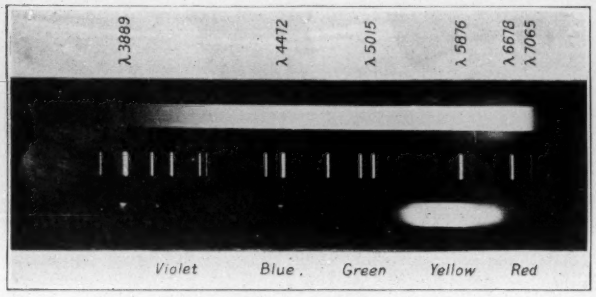
to match the luminous glowworm abdomen the figure 190-metre candles, or *.0190 lumens per square centimetre.*

In order to reduce this to lumens emitted per square centimetre we must first correct for the reflecting power of the white blotting paper which was used at *B,* namely, 76 per cent. Applying this we get for the specific luminous emission of the white surface, $.76 \times .0190 = .0144$ lumens per square centimetre.

Thus far the experiment merely tells us that *when viewed in a certain direction* the emission from a certain area of the glowworm *which is seen in projection* matches a diffusely emitting plane surface whose emission is .0144 lumens per square centimetre. In the experimental work there was no indication that the glowworm's emission was other than diffuse; that is, that the photometric match would not hold for any direction, so that the first qualification may be dismissed. But the matter of determining the true area of the emitting portion whose projection we observe is not so easy. If the luminous portion were a flat plate then the specific luminous emission would be exactly that of the illuminated blotting paper background. If the luminous portion were a hemisphere, the quantity in question,

according to relations derived from the theory of radiating surfaces, would be half that of the flat background; if half a cylinder, it would be $\frac{2}{\pi}$ times that of the background. The luminous abdomen of the insect is actually composed of a series of overlapping plates of convex curvature; the curvature is small, however, so that no serious error will be introduced in assuming them to be

FIG. 5.



Spectrogram of fire-fly light (lower spectrum), carbon incandescent electric lamp light (upper spectrum), helium vacuum tube (middle spectrum).

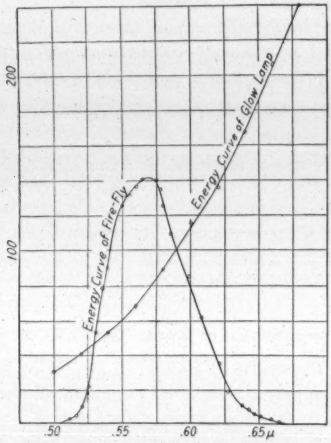
equivalent to a single flat plate. We shall, therefore, in what follows, adopt for the *specific luminous emission of the glow-worm*, the figure given directly by the experiment, namely *.0144 lumens per square centimetre*, merely bearing in mind that the true figure is probably a little lower. It may be noted that this value is of the same order of magnitude as that derived from Pickering's estimate of the intensity of a single flash.

Let us now consider this figure. Compared with the 500 of the tungsten filament or the 1.0 of a typical sky, it appears excessively low. This does not necessarily mean that it is too low to be useful, because most of our artificial light sources are of such high specific emission that their brightness must be reduced by the use of diffusing glassware or reflecting surfaces. Does it indeed still lie in the range of usefulness, or is the glowworm like those markers of phosphorescent radium containing

material, which can be seen but which are too weak to give useful illumination?

We can answer this question by considering the illumination due to an *extended luminous surface*, for obviously a "point" source of only $\frac{1}{30,000}$ the intensity of a tungsten lamp would be too weak for any use. Now it may be shown that if we take a

FIG. 6.



Energy distribution in radiation of fire-fly.

diffusely-radiating disc of specific luminous emission S, and of radius r, the illumination on a point in its axis, at distance d is

$$E = S\left(\frac{1}{1 + \frac{d^2}{r^2}}\right)$$

where E and S are expressed in the same units of area, *i.e.*, if S is in lumens per square centimetre, E also refers to square centimetres. For points off the axis E becomes smaller, but slowly enough so that we need not here take the decrease into account. The relation between E and $\frac{d}{r}$ is shown in Fig. 2. Let us at once substitute for S its value as determined from experiment, and in order the more quickly to correlate the result with practical illu-

mination figures, let us express it in lumens per square metre (metre candles). Taking the resultant figure, 144 lumens per square metre, we can compute at once from Fig. 2 that at $\frac{d}{r} = 1$ the illumination will be 72 lumens per square metre, at $\frac{d}{r} = 2$, it will be 29 lumens per square metre, at $\frac{d}{r} = 3$ it will be 14 lumens per square metre, etc.

It now only remains to compare these with illuminations which have been found satisfactory for various practical locations and occupations. A representative table is here reproduced.[3]

Illumination for Various Purposes.

	Meter Candles
Reading, U. S. Government Post Office minimum requirements	30
Clerical and office work	32–75
Drafting	50–100
Factory work, coarse	15–30
Factory work, fine	30–100
Corridors	3–10
Audience rooms	10–30

It will be seen that our figure for $\frac{d}{r} = 2$, namely, 29-metre candles, lies in the midst of these. It would be satisfactory for those cases which may be classified as general illumination. What does this mean in terms of space requirements? This is simply shown in Fig. 3, where, as a typical case, a room three metres in height is chosen with a central table at a height of one metre. Upon the ceiling is placed a disc of luminous material two metres in diameter. From our calculations it follows that the illumination on the table from such a ceiling panel would be quite adequate for many purposes. Increase in the size of the luminous ceiling panel, keeping the height the same, will increase the illumination up to a limit (for an infinitely large room) of 144-metre candles, which is well above any of the requirements set forth in the above table. This scheme of illumination will be recognized as identical with "deck lighting" or with the so-called "indirect" system, in which the effective light source is the bright ceiling.

The net result of this study thus shows that while the specific luminous emission of the glowworm is not of such a magnitude as to recommend its use for locomotive headlights or for intense

local lighting, it is, as it stands, of practical intensity for use in methods of lighting now in vogue. The *flash* of the ordinary fire-fly is much more intense than the glow of its larva, so that it is reasonable to suppose that the same process of light production would be capable of speeding up so as to require less space than is used in the manner shown in Fig. 3, practical though that arrangement is.

EFFICIENCY.

Knowing the specific luminous emission of the luminous organism we could at once obtain its *total luminous efficiency* if we knew the rate of consumption of energy or work per unit of luminous area. We would then have its lumens per watt, directly reducible to percentage efficiency by comparison with the maximum possible lumens per watt, a reasonably well-established constant of photometry.

Direct measurements of energy consumption in the glowworm or fire-fly, to say nothing of measurements restricted to the luminous portion, are as yet beyond the range of experiment. We can at best only arrive at an approximate idea of this element of the luminous efficiency by general considerations based on comparison with other organisms. Such a comparative estimate has been made as follows:[4] A man, weighing 75 kilograms, can do about 75 watts work continuously; that is, he has an output of one watt per kilogram. If it can be assumed that energy output in proportion to weight is the same for creatures as diverse as man and the glowworm, we arrive, by using .25 gram as the weight of the glowworm, at the figure .00025 watt as the probable total energy output of the insect. Now about $\frac{1}{10}$ of the glowworms total tissue is devoted to light production, so that we may assume at least $\frac{.00025}{10}$ or .000025 watts expended in light production. The area emitting light is about 10 square millimetres. Hence the work expended per unit of luminous area on those various assumptions is .00025 watts. Using the figure of the last section for the luminous emission, namely, .0144 lumens per square centimetre, we obtain for the total luminous efficiency

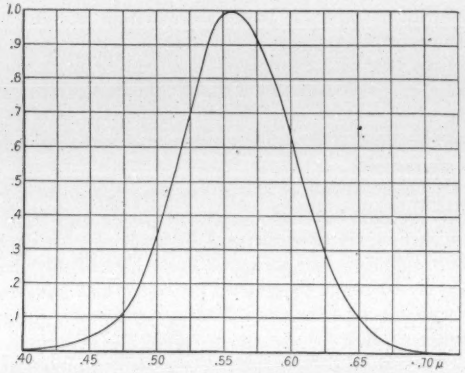
$$\frac{.0144}{.00025} = 576 \text{ lumens per watt.}$$

Comparing this with the 640 lumens per watt, which corresponds to 100 per cent. efficiency of light production, we get the striking

result that the *total luminous efficiency* of light production by the fire-fly (glowworm) is *90 per cent.*

Exception may be taken to the assumptions made in arriving at this figure, and it cannot claim to be more than a plausible approximation. The calculations do, however, make it seem probable that the luminous efficiency, even if not so high as 90 per cent., is nevertheless many times greater than that of our ordinary light

FIG. 7.



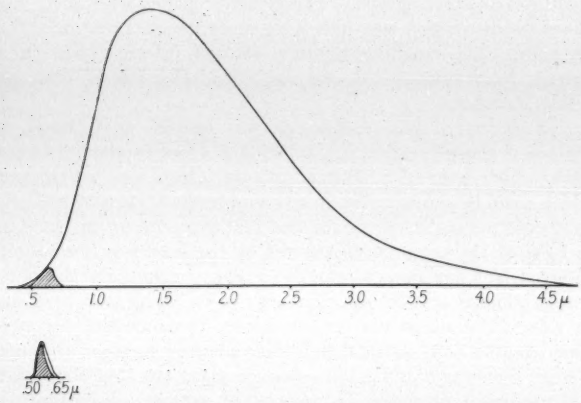
Luminous efficiencies of spectral radiations.

sources, for even if the figure is off by a factor of 3 or 4, or even 10, the efficiency would still be many times the 4 or 5 per cent., which is about the best we now accomplish artificially.

High total luminous efficiency implies that the radiational efficiency, and the radiant luminous efficiency, are both high. It would be of interest to verify this conclusion for each of these two efficiencies separately, if possible, and so strengthen the conclusion as to total efficiency. Determination of the radiational efficiency is, in the case of the glowworm or fire-fly, quite beyond our present measuring means. The denominator of the fraction (namely, energy consumed in light production) can only be guessed at by methods such as those of the preceding paragraphs, while the numerator—total radiated energy—is altogether too faint for quantitative measurement by any of the radiometers sensitive to the whole radiant spectrum, such as the thermopile

and the bolometer. We can at best merely decide that the energy radiated is enormously less than that from an equally bright light of any other type, or that possibly the luminous portion of the insect is warmer than the non-luminous. But when it comes to the *luminous efficiency of the radiation* we are much better off. In order to measure this it is only necessary to get satisfactory evidence as to *where* in the spectrum the radiation appears, and

FIG. 8.



Luminous efficiencies of carbon lamp (upper curve) and of fire-fly (lower curve) radiations. Area of outer curves are proportional to total radiation; areas of cross-hatched curves to light-evaluated radiations; the ratio of light-evaluated to total radiation is the luminous efficiency.

then to study the spectrum of the radiation at this point by some selective radiometer, which while not sensitive enough for general radiation measurements is adequate for quantitative work in the restricted spectral region. The possibility of doing this of course depends on the radiation proving to be of narrow spectral extent, and on the existence of a suitable selective radiometer. Fortunately both these conditions occur in this problem.

In order to find where in the spectrum energy is emitted by the fire-fly, two methods have been used, each of which has the property of integrating repeated small effects over a long interval of time. The first of these is *photography;* the second, is *extinction of phosphorescence.*[5] Photography, with panchromatic plates, covers the range of wave-lengths from .2μ (provided only

quartz optical apparatus is used) to .7μ. Extinction of phosphorescence covers the region from .5μ to 1.5μ. The two methods, as shown diagrammatically in Fig. 4, therefore overlap in the visible region, and extend our range of experiment well into the ultra-violet and infra-red.

The photographic experiment to find where the light emitted by the fire-fly lies in the spectrum consisted in placing a series of flashing fire-flies of the species *Photinus Pyralis* over the slit of a small quartz spectrograph. Panchromatic plates were used, the slit of the instrument was quite wide, and exposures continued for an hour. The resulting negative showed *intense action in a narrow band between .5μ and .6μ (Fig. 4) with no trace of action elsewhere.*

Extinction of phosphorescence was utilized as follows: A surface of phosphorescent zinc sulphide was first exposed to an arc light, which induced a phosphorescence which was visible and which could be photographed for several hours. Then by preliminary experiments, it was established that exposure of this surface to light of the wave-length emitted by the fire-fly in the visible spectrum was just about as effective in extinguishing the phosphorescent glow as was the same quantity of radiation anywhere out to 1.5μ. The actual test on the fire-fly then consisted of two experiments; first, its total light was allowed to shine through a small diaphragm and a thin sheet of glass (to stop body heat and moisture) upon the phosphorescent surface. Exposure of only twenty minutes' duration was sufficient to noticeably darken the phosphorescence. Then the experiment was repeated, but this time with a red glass interposed which was opaque to the visible fire-fly light, yet transparent to the infra-red as far as 1.5μ. An exposure of several hours through this glass produced *no trace of action.*

These two experiments showed very conclusively that within the region from the ultra-violet at .2μ to the infra-red at 1.5μ the *radiation of the fire-fly is restricted to a narrow band in the visible spectrum.* While the experiments do not definitely prove that this is the only radiation, it is highly improbable radiations would be emitted outside these spectral regions, for such radiations would be absorbable by the water of the insect's tissues and by the atmosphere. We are therefore justified in proceeding upon the assumption—subject to possible modification by measuring

means yet to be developed—that the only radiation of the fire-fly is this narrow band in the visible spectrum.

It now remains for us to study in detail the character of this radiation. How advantageously is it placed in the visible region, for the requirements of vision? To investigate this, use was again made of photography,[6] but this time with a spectrograph of large dispersion, with comparison photographs from which not only exact position but exact distribution of energy could be determined. Fire-flies were held against the spectrograph slit for several hours, one insect after another, as each became exhausted or refused to flash further. Then on the same plate was photographed a line spectrum containing numerous well-known wave-lengths, and also, on this and other plates, a series of spectra of various known intensities, from a light source of known energy distribution. For this latter a carbon incandescent lamp was selected, operated at a definite voltage, and its energy distribution measured through the spectrum as a separate experiment. A photograph of the fire-fly spectrum made in this way is shown in Fig. 5. It will be noted how definitely the light is restricted to a narrow region around .56μ–.57μ, the most luminously efficient part of the spectrum. The next step was to measure the densities of the fire-fly and carbon lamp comparison spectrograms, wave-length by wave-length. This done it was possible by noting the points of coincidence of the fire-fly spectrum densities with one or other of the carbon lamp spectra to establish the relative intensity values of the fire-fly spectrum and the carbon lamp spectrum, and then, by simple proportion, to determine the spectral distribution of energy in the emission of the fire-fly. Fig. 6 shows the result of carrying through this process. For comparison, the energy distribution of the carbon lamp is also shown; that is, as far as the photographic plate and glass prism spectrograph could record it. Its spectrum actually extends many times as far beyond the red, and is still measurable beyond the blue end of the photographed spectrum in the figure.

Before we can find how efficient is the fire-fly radiation, we must know the relative luminous efficiencies of the various radiations. These are shown in Fig. 7 with such a scale of ordinates that the most efficient radiation, at .56μ, is rated 100 per cent. This means that radiation consisting entirely of a monochromatic band of this wave-length would give the greatest possible amount of

illuminating power for a given expenditure of energy as radiation. To either side of .56μ the efficiency falls off rapidly, until at and beyond the ends of the visible spectrum it is of course zero. If now we multiply each monochromatic energy emission in Fig. 6 by its efficiency, we get a curve whose area will, in comparison with the unweighted curve, give the luminous efficiency of the radiation. This process is carried through first in Fig. 8 for the " 4-watt " carbon incandescent lamp. The ratio of the shaded (light evaluated) to the unshaded (total radiation) curve is .0045; that is, the *luminous efficiency of the radiation from the carbon lamp is less than one-half per cent.* When we apply the same process to the fire-fly radiation Fig. 6, we find *its efficienty to be over 80 per cent.* The exact figure depends upon the species of fire-fly chosen, since the position of the emission band varies somewhat (it is farther toward the blue in the Pennsylvania species whose glowworm was studied, than in the species investigated for the character of the flashing light) and upon the spectral luminous efficiency curve used, *e.g.*, corresponding to high or low illumination. Whether or not any fire-fly has developed absolutely the most efficient light for the use of the *human* eye is not so significant, except from the standpoint of comparative anatomy, as is the fact brought out by shifting the emission curve of Fig. 6, so that its maximum coincides with the maximum of luminous efficiency When this is done it appears that *the fire-fly has developed a type of radiation, which, if placed in the spectrum symmetrically about the wavelength of maximum luminous efficiency, will be of at least 95 per cent. efficiency.*

Summarizing at this point these investigations of the fire-fly's luminous efficiency, we see that whether we study its total or its radiant luminous efficiency the figure arrived at is in excess of 80 per cent. These two efficiencies cannot both be so high unless the *radiational efficiency* is of the same order of magnitude; that is, the process of transforming its bodily energy (input) into radiation (output) must be of the same order of efficiency as in the vacuum incandescent lamp. Thus viewed from every aspect, the conclusion (subject to possible restrictions which have been pointed out) is that the *efficiency* of light production in the fire-fly is comparable with the *inefficiency* of our best processes of artificial light production. In our ordinary illuminants, light is

a by-product of a process of heat dissipation; in the fire-fly heat is the by-product of a process of light production.

QUALITY.

It is evident from Fig. 5 that the color of the light given out by the fire-fly is very different from that of an ordinary illuminant, such as daylight or incandescent electric light. It is practically a monochromatic yellow-green. Other colors, being absent from its spectrum, would fail to be visible in objects illuminated by it. The objects in the room imagined in Fig. 3 would all appear as of one color, varying only in intensity. The effect would be like that produced by the old experiment of lighting a room solely by a salt impregnated alcohol flame, only not quite so ghastly, since there is a little orange and blue-green in the light of the fire-fly. In respect to color distribution, it would be rather worse than the mercury arc.

For the purposes of color discrimination or for securing a light of "pleasant" character, the narrow band of emission would have to be widened until it became of the length of the visible spectrum. It is interesting to note that were this done and the energy distribution in the visible spectrum made like that of sunlight, the resultant radiation would still have a luminous efficiency of 40 per cent.; as compared with 14 per cent. for real sunlight.

One advantage of fire-fly light, just as it stands, however, would be in the discrimination of fine detail. Being monochromatic it reduces that diminution of visual resolving power which is caused by the eye's chromatic aberration. *Its color—yellow-green—is just that for which maximum visual acuity is realized.* In this respect it would surpass any artificial light now available.

SUMMARY.

While experimental difficulties do not permit a complete and accurate analysis of all the factors which enter into the evaluation of the fire-fly as an illuminant, it is clear that it does produce a light of sufficient intensity for human use, of a quality which would make it advantageous for many kinds of work. Its efficiency, while less accurately known than its other factors, is undoubtedly exceedingly high, since study of both its total and its radiant luminous efficiency indicate figures of 80 per cent. or better. The same kind of emission, spread through the whole

visible spectrum, would still have an efficiency many times greater than any artificial illuminant.

By way of conclusion we may repeat the words of Langley,[7] one of the first to attempt quantitative measurements of the firefly, when he says: "There seems to be no reason why we are forbidden to hope that we may yet discover a method (since such a one certainly exists and is in use on a small scale) of obtaining an enormously greater result than we now do from our present ordinary means for producing light." It has been the object in this paper to indicate the size of Langley's "enormously greater result."

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[1] W. H. Pickering: *Nature*, **97**, p. 180, April 27, 1916.
[2] Ives and Jordan: *Lighting Journal*, Feb., 1913, p. 47.
[3] Selected from "Illuminating Engineering Practice," McGraw Hill, 1917, p. 61.
[4] McDermott and Ives: *Lighting Journal*, March, 1914, p. 61. (The result there published is in error by the factor π.)
[5] Ives: *Physical Review*, Dec., 1910, p. 637.
[6] Ives and Coblentz: *Trans. Illuminating Eng. Soc.*, Oct., 1909, p. 675.
[7] Langley and Very *Smithsonian Misc. Coll.*, n. 1258.

A New Method of Using X-Rays in Crystal Analysis. G. L. CLARKE and WILLIAM DUANE. (*Proc. Nat. Acad. Sciences*, May, 1922.)—An essential feature of this method is the use of a continuous spectrum of X-rays and not merely a line spectrum. The crystal, either powdered or intact, is put at the centre of an X-ray spectrometer which has an ionization chamber. It reflects at certain positions a considerable part of the incident beam of X-rays into the chamber. When a set of parallel planes of the crystal comes into a definite direction, the reflected beam is of maximum strength. The crystal is turned and the strength of the currents caused in the ionization chamber by the reflected beam is measured from each position. From the angles between the positions for which the ionization reaches maxima it is possible to infer the angles between the crystal planes producing the reflection. Great accuracy in the measurement of crystal angles is obtained by this method. When a crystal of KI was investigated the angles between maxima came out 44.96°, 18.37° and 26.52°, "which correspond very closely with the angles between some of the principal planes in a cubic lattice, namely 45°, 18.43° and 26.57°."

It is very interesting to note the name of a descendant of Benjamin Franklin at the head of article after article recording advances in physics.

G. F. S.

THE EFFECT OF ABSORBED GAS ON THE CONDUCTIVITY OF GLASS.*

BY

V. BUSH, Eng.D., and L. H. CONNELL, S.B.

Massachusetts Institute of Technology.

THIS paper presents the results of an investigation on the electrical properties of glass carried on during the past two years in the Research Laboratories, Department of Electrical Engineering, Massachusetts Institute of Technology. Briefly, these results show that gases, in particular water vapor, penetrate throughout the volume of glass and quartz, and radically affect their volume conductivity.

Langmuir [1] has measured the amount of gas removed from glass by heating in vacuum. He found this gas to consist principally of water vapor and also showed that the total amount liberated varied with temperature up to the softening point of the glass. On the assumption of absorption, the amount of water obtained corresponded, for a representative specimen, to a surface layer 55 molecules deep. Some penetration is hence evident; and Langmuir concludes that a solution of the water in the glass takes place. The results of a number of other investigations [2] indicate a similar conclusion. The present investigation was undertaken to determine whether penetration occurred throughout the volume, and whether some light could not be thrown upon the electrical conductivity of vitreous materials.

The specimens on which conductivity measurements were made were prepared as shown in Fig. 1. A tube of the material to be tested was closed at one end. Electrodes were placed inside and outside by copper plating. Care was taken that these should adhere firmly to the glass. Small parts of the outer electrode in numerous places were removed to render bare the glass underneath. The specimen was then mounted, as shown, in a tube which could be exhausted. Three guard rings were plated on.

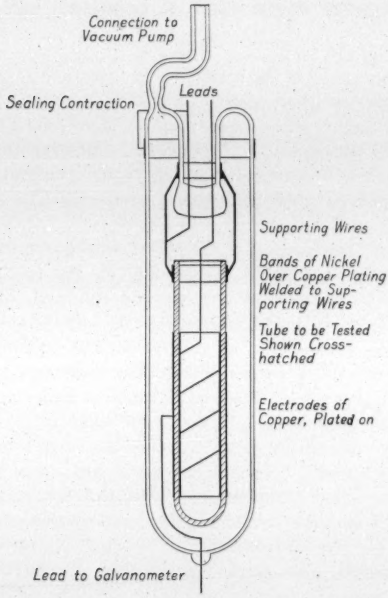
* Communicated by Dr. V. Bush.

[1] *J. A. Chem. Soc.*, **38**, 2283 (1916); *Trans. A.I.E.E.*, **32**, 1921 (1913).

[2] Dushman, G. E., *Review*, **24**, 246 (1921), gives an excellent summary of this previous work.

These rings were so placed and connected as to prevent current passing through the measuring instrument except that which flows from outer to inner electrode through the body of the specimen. The guard ring on the specimen itself was placed close to the outer

FIG. 1.


Connection to Vacuum Pump
Sealing Contraction
Leads
Supporting Wires
Bands of Nickel Over Copper Plating Welded to Supporting Wires
Tube to be Tested Shown Cross-hatched
Electrodes of Copper, Plated on
Lead to Galvanometer

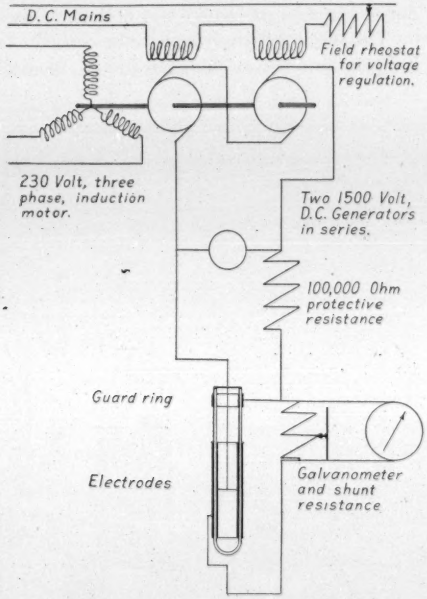
electrode in order that the measurement of volume conductivity might not be grossly affected by changes in the effective area of the electrodes due to variations in surface conductivity.

The diagram of connections is shown in Fig. 2. A generator was used capable of delivering 3000 volts constant potential. The galvanometer used was calibrated from time to time, and gave an average constant of 1.722×10^{-9} amperes per mm. deflection, which did not vary enough to require special attention.

The layout of apparatus was as shown in Fig. 3. Insulation was obtained by suspending parts at high potential by silk threads

from glass rods. This insulation was tested from time to time by breaking the connection to the outer electrode immediately adjacent to the tube, taking the shunt off the galvanometer, and applying full voltage. A deflection under these conditions greater

FIG. 2.

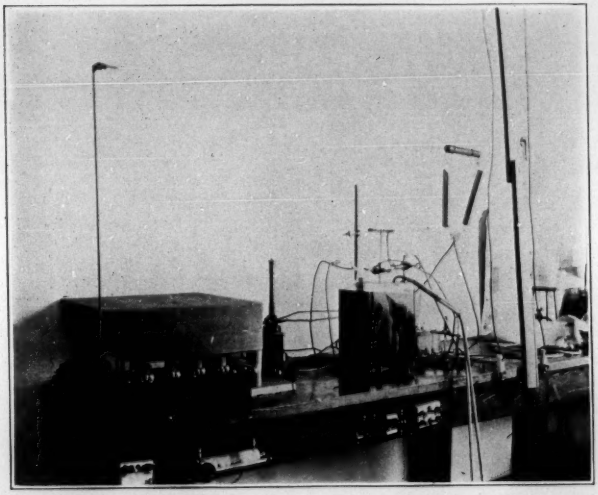

D. C. Mains
Field rheostat for voltage regulation.
230 Volt, three phase, induction motor.
Two 1500 Volt, D.C. Generators in series.
100,000 Ohm protective resistance
Guard ring
Electrodes
Galvanometer and shunt resistance

than 3 mm. was not tolerated. As the measurements were carried on with a deflection of approximately 100 mm., and a shunt ratio of about 10 : 1, it is believed that ample insulation was provided.

Constant temperature on the sample was maintained by immersing the containing tube in oil to within one centimetre of the top, thus leaving the lead to the inner electrode entirely in air. The temperature of the oil was maintained constant at $25.00 \pm .05$ degrees Centigrade by a heater and automatic control. Preliminary curves of resistivity against temperature for representative specimeans of glass had a slope of approximately 10^{10} ohms per centi-

metre cube per degree Centigrade at the temperature of 25° C. chosen for the measurements. For the preliminary work we are indebted to Mr. F. C. Tsu and S. L. Yang. The measured values of resistivity at 25° C. were always above 10^{11} ohms per centimetre cube, and as temperature was held well within .1 degree, the error due to temperature change was probably always less than 1 per cent. The specimens were kept in the constant temperature bath for half an hour before taking readings, to make sure the

FIG. 3.

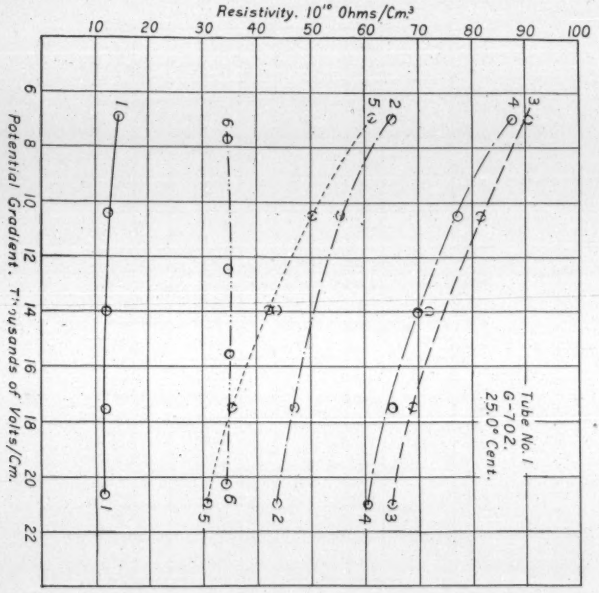


specimen itself had reached the desired temperature. The effectiveness of the guard rings was investigated on typical samples by transferring the galvanometer to the guard ring lead. The greatest current measured in this lead was about 20 per cent. of the current flowing to the outer electrode. Surface conduction on the specimen results in increasing the apparent area of the electrodes, but the error from this source may be expected to be less than 10 per cent. When, during a measurement with the galvanometer connected as in Fig. 2, the lead to the guard rings was

opened, the current flowing through the galvanometer usually increased about 10 per cent. This again indicates that the stray current error is reasonably small.

With each specimen the following procedure was carried out as far as possible:

FIG. 4.



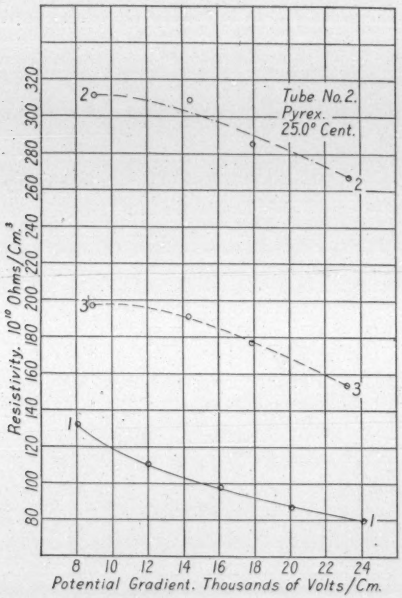
1. The specimen, mounted in its containing tube, was washed in ether and dried by warm air. It was then brought to constant temperature and its resistance measured for various values of applied potential.

2. The containing tube was then exhausted with a Langmuir pump and heated to 350° C. until no further gas was evolved. It was then sealed off the pump. After cooling, it was brought to constant temperature, and resistance measurements were repeated for the same values of applied potential as were used previously.

3. The seal in the outer tube was now cracked to allow air to enter; and another curve was taken as soon as possible. This was intended to detect any error which might be present due to gaseous conduction in a poor vacuum.

4. After the lapse of a few hours or days, the measurements of resistance were again made.

Fig. 5.



The results on the first specimen are shown in Table I. This was a piece of G-702 Corning glass. The values given in this table are plotted in Fig. 4. Curve 1 applies to the untreated tube. During exhaustion the outer tube cracked when the temperature reached 300° C., but a curve was immediately taken and is shown at 2. The outer tube was repaired and exhaustion at 350° C. was then completed. Curve 3 was obtained immediately after this exhaustion. The seal was then cracked to admit air. Curve 4

TABLE I.

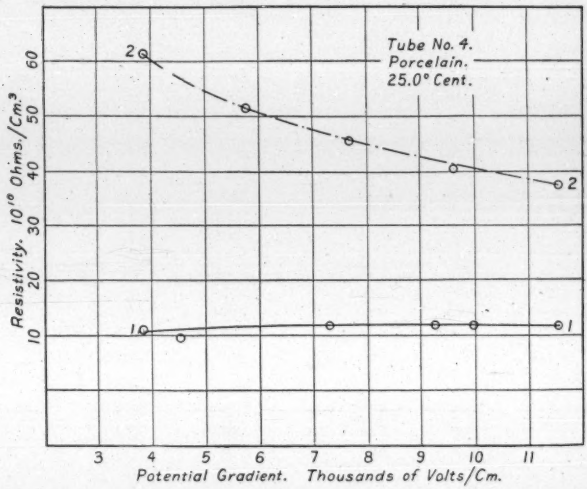
Tube No. 1 *G702* 25.0° C.

Inside Diameter, 1.58 cm.
Outside Diameter, 1.87 cm.
Length of Electrodes, 10.0 cm.

	Impressed Voltage Volts	Resistance Ohms	Potential Gradient Volts/cm.	Resistivity Ohms/cm.³
	2950	314×10^6	20600	11.90×10^{10}
	2510	317	17520	12.00
(1)	2005	322	14000	12.20
	1500	333	10460	12.62
	1000	337	6980	14.30
	3000	1150×10^6	20940	43.6×10^{10}
	2500	1240	17440	47.0
(2)	2000	1160	13960	43.9
	1500	1470	10460	55.7
	1000	1720	6980	65.1
	3000	1720	20940	65.1×10^{10}
	2500	1820	17440	69.0
(3)	2000	1900	13960	72.0
	1500	2160	10460	81.8
	1000	2390	6980	90.5
	3000	1600	20940	60.6
	2500	1720	17440	65.1
(4)	2000	1845	13960	70.0
	1500	2040	10460	77.4
	1000	2310	6980	87.5
	3000	812×10^{-6}	20940	30.8×10^{10}
	2500	923	17440	35.4
(5)	2000	1110	13960	42.1
	1500	1330	10460	50.4
	1000	1620	6980	61.4
	2890	902×10^6	20200	34.2×10^{10}
	2670	827	18640	31.3
	2450	995	17100	37.7
	1780	900	12420	34.1
	1335	596	8320	22.6
(6)				
	2890	908×10^6	20200	34.4×10^{10}
	2225	923	15520	35.0
	1780	920	12420	34.8
	1112	914	7760	34.6

was taken about eighteen hours later. After three days, the results were as shown in Curve 5. A measurement at 3000 volts, taken from time to time during the next few weeks, showed the values given in Curve 5 to remain substantially constant.

FIG. 6.



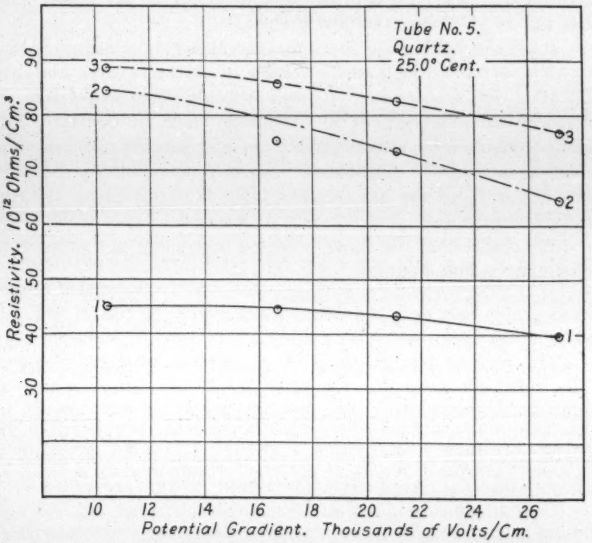
As a further experiment, this tube was then placed in an iron pipe and subjected to three pounds steam pressure for two days. The outer tube cracked during this treatment, so that the specimen itself was placed in contact with the oil to obtain the values shown in Curve 6. This last curve is probably unreliable. It indicates interesting possibilities which should be studied.

It will be noted that the measured values of volume resistivity were increased in the ratio of approximately 6 : 1 by the removal of the water vapor and other gas from the glass. Some of this change is no doubt due to an alteration in surface conductivity as noted above; but only a relatively small part can be accounted for in this manner. There is evidently a large change in the volume conductivity when heated in vacuum. Upon subsequent exposure to the air the resistivity decreased slowly, but did not

reach its original value. These results suggest interesting scientific and technical possibilities.

Other specimens were similarly tested. In Fig. 5 are shown the results for "Pyrex." Curve 1 was taken on the fresh specimen,

FIG. 7.



Curve 2 after exhaustion at 360° C., and Curve 3 after the specimen had been opened to the atmosphere for three days. The tube was then broken accidentally.

Fig. 6 gives the results with a specimen of porcelain. Curve 1 applies to the raw specimen, and Curve 2 after exhaustion at 350° C. This specimen also met with an accident.

Fig. 7 was taken with fused quartz. The precision of the results on quartz was less than on glass as the resistivities measured were much higher. Curve 1 was taken on the new specimen, Curve 2 after exhaustion at 350° C., and Curve 3 after subsequent exposure to the air for two days. Several times during the next two months single points were taken, and were always found

to lie between Curves 2 and 3. Apparently the resistivity of quartz does not decrease rapidly on exposure to air after vacuum treatment.

As a further check on results the dielectric loss in one specimen was measured at 1000 cycles per second before and after vacuum treatment. It was found to decrease by about 20 per cent. This has not as yet been carefully studied.

It is believed that the above measurements show definitely that gases penetrate throughout the volume of glass or quartz, and thus affect its electrical conductivity and probably other properties. A considerable improvement in insulating value or dielectric loss can be obtained by vacuum treatment and part of this improvement is apparently permanent. Some penetration of moisture into the body of the glass occurs from the atmosphere at ordinary temperatures.

We realize that the above is only a beginning, and propose to continue the investigation.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
April 17, 1922.

The European Commercial: A New "World" Newspaper.—The following from *The Chemical News* will be interesting to American business men. An important step in the rehabilitation of European trade, and indeed the trade of the entire world, will be the publication, under British auspices, in Vienna, in a few weeks' time, of a new periodical, claiming to possess "an authority and a status of an altogether exceptional character."

Under the imposing title of *The European Commercial,* this ambitious venture has the approval and will enjoy the active support of most of the European Governments, will be accorded special facilities for the collection of authoritative news, and will circulate through Government circles. With a staff of commercial experts selected from the leading markets of the world, and with local editors and correspondents in every important city in Europe, it will at once assume, so its promoters claim, an unchallengable position as a real World Newspaper.

Although Vienna has been selected as the publishing centre, on account of its hospitality, its cosmopolitan character, and its favorable situation, *The European Commercial* will be printed in English. It will conduct no propaganda, its mission being simply to bring business men together and to give them facts and figures. To maintain strict impartiality among the various countries, the advertising space will be rigidly rationed.

H. L.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

DURABILITY OF SOLE LEATHER FILLED WITH SULPHITE CELLULOSE EXTRACT.[1]

By R. C. Bowker.

[ABSTRACT.]

THIS paper describes the preparation of four lots of leather used to determine the comparative durability of sole leather filled with sulphite cellulose extract and sole leather filled with ordinary vegetable tanning materials such as chestnut wood and quebracho extracts. Several hides were used in the preparation of each lot, and alternate sides were filled with the sulphite cellulose extract. Each pair of soles contained one sole prepared by each method, both of which were cut from the same hide and from similar locations.

The results of actual service tests are presented which show that the average wear of the leather filled with sulphite cellulose extract was 9.08 days per unit thickness and of the ordinary leather 9.06 days.

Complete chemical analyses of both the new and worn soles are also given.

The general conclusions are that there is no difference in the two leathers as reflected by the chemical analyses; that sole leather filled with sulphite cellulose extract is as durable as leather filled with chestnut wood and quebracho extracts, and that the former could well be used in place of the latter materials, thereby conserving them for the actual tanning of leather for which they are more suitable than sulphite cellulose extract.

SOURCES OF ELEMENTARY RADIO INFORMATION.[2]

[ABSTRACT.]

A VERY considerable number of persons are interested in the operation of radio stations, who are not directly concerned with

* Communicated by the Director.

[1] Technologic Paper No. 215.

[2] Circular No. 122.

the operation of either Government or regular commercial radio stations. Some are interested in maintaining a private system of radio communication over comparatively short distances. Many are interested in radio because it offers a very fascinating experimental field. Different kinds of useful information, such as weather reports, market reports, time signals, and music, and other entertainment are transmitted daily by radio, and are received by many persons in all parts of the United States.

The recent developments in radio communication have been so rapid that much important radio information has not yet been collected in books, but must be sought in periodicals and other sources. A number of important books have appeared very recently and are not yet generally known. The Bureau of Standards is constantly receiving requests for radio information. The same information is called for by many of the inquiries received, and in order to facilitate the answering of such inquiries, this Circular has been prepared. This Circular gives information concerning radio periodicals, Government radio publications issued by various bureaus, radio books, issued by various publishers, radio laws and regulations, call letters, and safety precautions to be observed at radio stations, and answers a few of the most usual elementary questions concerning radio communication which are asked by the novice.

The periodicals devoted primarily to radio communication which are now available may be divided into three general classes. About half a dozen periodicals which have been in existence for two years or more are devoted to the interests of the radio amateur, that is, to the interests of the person who wishes to make radio experiments and to develop his own apparatus and often to transmit and receive radio telegraph messages over long distances, as from the Atlantic Coast to the Pacific Coast. There are two or three periodicals devoted to radio which are intended primarily for the professional engineer and scientist and contain papers which are usually of advanced technical interest. In addition, there is a third class which has very recently come into existence which is intended primarily for the radio novice, that is, the person who has only comparatively little familiarity with electrical and radio apparatus, but wishes to receive certain information and entertainment transmitted by radio, usually by radio telephony. Prior to 1921, there were only a comparatively few persons inter-

ested in radio from the novice point of view. The recent development of broadcasting by radio telephony has caused a very large number of persons to install radio receiving equipment. In the course of three months, seven new periodicals, intended for the novice, have been established, and it is expected that others will appear shortly.

The United States Department of Commerce, Bureau of Navigation, issues a monthly periodical called the *Radio Service Bulletin*, which will be found of interest to every person engaged in radio communication. The subscription price is twenty-five cents per year, and orders may be placed with the Superintendent of Documents, Government Printing Office, Washington, D. C.

The Bureau of Standards has prepared an elementary textbook, Signal Corps Radio Communication Pamphlet No. 40, "The Principles Underlying Radio Communication." This book contains 600 pages and more than 300 illustrations, durably bound in fabrikoid. Every person interested in radio communication will find this book useful. A copy can be purchased for one dollar from the Superintendent of Documents, Government Printing Office, Washington, D. C.

The Bureau of Standards has prepared a considerable number of professional Scientific Papers on radio subjects. These papers are listed in this Circular.

Information is given regarding the safety precautions which should be observed in radio installations. The rapid development of the radio art has required a revision of the rules for radio installations made by the National Board of Fire Underwriters. Sources of information are given from which particulars may be obtained about new rules proposed by the Underwriters.

The United States radio laws provide that in order to operate a transmitting station, both a *station* license and an *operator* license must be secured. In the United States, no station license is required for a station used only for reception. This Circular gives information regarding the granting of both station licenses and operator licenses, including the various grades of licenses of each kind which are granted. Information is also given regarding the Canadian radio laws, which differ considerably from those in force in the United States.

This Circular also gives information regarding call letters assigned to Government, commercial and amateur radio stations

in the United States. Separate call books are sold by the Superintendent of Documents, Government Printing Office, Washington, D. C., for amateur stations and commercial and Government stations, and information is given as to the proper method of securing each of these call books.

NOTES ON STANDARD WAVE-LENGTHS SPECTROGRAPHS, AND SPECTRUM TUBES.[2]

By W. T. Meggars and Kelvin Burns.

[ABSTRACT.]

I. *Standard Wave-lengths in the Cadmium Spectrum.*—The wave-lengths of thirteen lines in the spectrum of tubes containing cadmium vapor at low pressure are measured relative to the primary standard (6438.4696A) by means of the Fabry and Perot étalon interferometer. The adopted values in International Angstrom units are as follows:

2980.6216	3610.5098
3080.827	3612.8748
3133.167	4662.3525
3252.5248	4678.1504
3403.6529	4799.9139
3466.2010	5085.8230
3467.6559	6438.4696

The probable error in most of these values is less than 0.001 A, and evidence that the wave-lengths derived from spectrum tubes are reproducible is presented. Constant frequency differences which define the separation of subordinate series limits are established:

$$2p_1 - 2p_2 = 1170.866$$
$$2p_2 - 2p_3 = 542.104$$

II. *A Quartz Rock Salt Spectrograph.*—An instrument whose optical parts consist of quartz and rock salt is described. This spectrograph was designed for photography of interference phenomena in the ultra-violet, but is also serviceable in the visible spectrum and has certain advantages (larger dispersion, flatter

[2] Scientific Papers, No. 441.

field, partial achromatism) over the usual types of quartz spectrographs for investigating the shorter waves.

III. *A Stigmatic Concave Grating Mounting.*—The Wadsworth mounting in which the slit is, in effect, placed at infinity with the aid of an auxiliary mirror, thus filling the concave grating with parallel light, gives spectral images which are practically free from astigmatism. This permits the use of diaphragms in front of the slit for the photography of comparison spectra in juxtaposition, and makes it possible to study the spectra of interferences, or of localized parts of sources whose images are focussed on the slit. Compared with the Rowland type of mounting, it requires only about one-fourth the space, and although the dispersion is reduced to about half, the intensities of the spectra are increased more than four-fold. The characteristics are outlined and detailed drawings of the apparatus are reproduced.

IV. *The Preparation of Spectrum Tubes.*—Instructions and suggestions are given for the preparation of Plücker tubes commonly required for optical demonstration, testing and research. The remarks apply especially to tubes containing hydrogen, nitrogen, oxygen, helium, neon, and argon. It is sometimes inconvenient or impossible to purchase such tubes ready made, and it is pointed out that laboratories possessing a good vacuum pump and a glass blower can easily prepare their own tubes.

DURABILITY OF CEMENT DRAIN TILE AND CONCRETE IN ALKALI SOILS; THIRD PROGRESS REPORT (1919–20).[4]

By G. M. Williams.

[ABSTRACT.]

THE third progress report on the investigation of the durability of cement drain tile and concrete exposed to alkali soils and waters gives an account of the condition in 1919 and 1920 of experimental drains laid in western alkali districts in 1913, and of large concrete blocks similarly exposed in 1915. Both drain tile and concrete blocks were made up in sufficient quantity and variety to be representative of all qualities, and were installed in typical alkali sections of the arid belt from New Mexico to Montana.

[4] Technologic Paper No. 214.

With reference to drain tile the following tentative conclusions have been drawn:

1. The use of cement drain tile in soils where sulphates occur in considerable quantities is hazardous. In certain localities the best quality of tile disintegrated within six years.

2. Porous or permeable tile, made from lean or dry mixtures, are subject to disintegration in sulphate waters of relatively low concentrations.

3. Disintegration of mortar or concrete in sulphate waters may be due in part to physical forces arising from crystallization of salts in the pores, but it is primarily due to chemical attack upon the cement.

4. In the best quality of tile the outer skin may sometimes remain apparently unaffected, at the same time allowing the alkali water to pass through and attack the mass underneath.

5. In tile of given quality exposed to sulphate waters, the disintegrating effect seems to vary with the concentration.

6. Tile made-by-hand or with the packer-head type of machine, and of sufficiently dry consistency to permit immediate removal of the molds, are less resistant to alkali action than tile of a wetter consistency which requires their retention in the molds for a period of hours.

7. Tile cured with steam seem to be no more resistant to alkali attack than those cured by systematic sprinkling. Tar and cement grout coatings were not effective in protecting the tile.

8. If cement drain tile are to be used in soils or waters containing more than 0.1 per cent. of sulphates, careful consideration should be given to sub-surface conditions, the quality of tile to be used, etc.

9. Quality of cement drain tile can best be measured by permeability tests. There appears to be little definite relation between permeability and the related factors of porosity, absorption, and density.

With regard to concrete the following tentative conclusions have been drawn:

1. Materials of good quality and proper workmanship are of great importance in the fabrication of concrete exposed to alkali soils and waters.

2. Surface action on concrete blocks of good quality after one year's exposure has in most cases been progressive.

3. The extent and rapidity of disintegration depends upon concentration of soluble sulphates.

4. Disintegration of concrete blocks containing reinforcing rods has in some cases been aided by corrosion of the rods and consequent splitting of the concrete.

5. Concrete structures exposed to alkali waters should be given all possible protection by drainage.

6. Concrete of the best quality will disintegrate if exposed to sufficiently high concentrations of alkali, such as were encountered in some of the locations where the test blocks were installed.

7. So far as the tests indicate, the resistance to alkali action of mass concrete, made of the same aggregates and exposed to the same concentrations, varies with the cement content or richness of mix. This again seems to indicate that strength and permeability, rather than absorption, are the governing factors in determining the quality and durability of concrete under alkali exposure.

The paper carries two appendices, one containing a summary of the absorption tests on samples of all types of drain tile used in the investigation, and the other a discussion of the occurrence of soluble salts in the soil and their action on cement and concrete.

POWER LOSSES IN AUTOMOBILE TIRES.[6]

By W. L. Holt and P. L. Wormeley.

[ABSTRACT.]

THE Bureau of Standards has undertaken a general investigation of automobile tires and inner tubes, and in connection with this work a rather comprehensive program has been laid out for dynamometer tests, to study among other things the power losses or energy dissipated into heat in tires operated under different conditions of axle load, inflation pressure, speed, temperature, and tractive effort. Preliminary tests have been made to determine the influence of these factors, which, aside from matters of design, are the principal items affecting the power loss in a tire. A continuation of the work will involve problems of design and construction, the influence of "over-size" tires and of "cord tires" on power losses, mileage, and general efficiency of operation. An

[6] Technologic Paper No. 213.

investigation will be made of inflation pressures as affecting the efficiency and economy of tire operation. Tests will be made to determine the effects of tire fillers, shields, puncture proof tubes, etc., and the properties of cushion tires will be studied.

The equipment consists of two Sprague electrical absorption dynamometers having a capacity of 20 horsepower at 600 r.p.m. and 10 horsepower at 150 r.p.m. One dynamometer is operated as a motor carrying on its shaft a wheel and the tire to be tested. The other dynamometer is operated as a generator carrying on its shaft a smooth straight face iron drum 40 inches in diameter. The motor is mounted on a movable carriage, the arrangement being such that by the application of weights to a bell crank lever the tire is forced against the drum with a pressure corresponding to the desired axle load. In this way the tire and drum constitute a friction drive by means of which the motor drives the generator. The field pole frame of each dynamometer is supported in ball bearings concentric with the armature shaft, and when in operation the magnetic drag or torque is measured on a Fairbanks scale. Each dynamometer is provided with a centrifugal tachometer which indicates the approximate speed in r.p.m. and with a mechanical revolution counter operated by a magnetic clutch. The revolution counters are so designed that they may be read to the nearest one-tenth revolution of the tire or drum. The control panel is completely equipped for regulating the motor speed and generator load. Resistance grids are provided for absorbing the power generated. A switch is provided for operating simultaneously a stop watch and the revolution counters.

METHOD OF DETERMINING POWER LOSS

The distance from centre of shaft to knife edge on each element is 15.756 inches, so that the power output of the motor and the power input of the generator are computed by the formulas

$$HP_1 = \frac{T_1 N_1}{4000} \quad \ldots\ldots (1),$$

and

$$HP_2 = \frac{T_2 N_2}{4000} \quad \ldots\ldots (2).$$

Where T_1 = scale reading of motor element in pounds (corrected for windage).

T_2 = scale reading of generator element in pounds (corrected for windage).

N_1 = Revolutions per minute of tire.
N_2 = Revolutions per minute of drum.

The power loss in a tire is given by the equation:

$$HP_1 - HP_2 = \frac{T_1N_1 - T_2N_2}{4000} \text{ (horsepower)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3).$$

This loss is due partly to deformation of the tire, and partly to slip. The part due to deformation represents heat developed in the tire, and the part due to slip represents heat developed at the surface of contact between tire and drum.

Perception of the Direction of Sounds and Some Technical Applications. W. KUNZE. (*Physikal. Zeit.*, December 1, 1921.)—Our ability to determine the direction from which sounds come depends upon the simultaneous use of both ears. At the two ears there are possible differences in three physical features of sounds arriving from the same source, *viz*—intensity, phase and instant of reception. The two former differences have usually been called on to furnish an explanation of the perception of direction, but the attempt has not been successful. On the other hand, the explanation founded on the interval between the arrival of the sound at the two ears and published by Hornbostel and Wertheimer in 1915 is congruent with the facts. These men experimented with noises, instead of with tones, as was done by Rayleigh and his school.

If the interval is zero, then the sound is perceived as directly in front or behind, that is, in the median plane of the head. The same judgment is formed for time intervals up to .00003 sec., the time required for the sound wave to traverse about one centimetre in air. As the interval grows beyond .00003 sec. the sound is perceived to come more and more from the side until it seems in the line joining the ears when the interval is .0006 sec. or over. Of course if the interval is made too great, the two sounds will be heard as separate impressions. In .0006 sec. the wave travels about 21 centimetres in air, and it might be supposed that this is the distance from one ear to the other or, perhaps, half the perimeter of the head, but this is not the case. The 21 centimetres seems to be an empirical constant of unknown significance. This constant should be larger for an elephant than for man, and the animal ought to be able to determine direction more precisely than man. It is, however, possible to use a longer base for sound observations by setting two artificial receivers more than 21 centimetres apart and connecting them to the

two ears by tubes of equal length. Suppose that with the unaided ear the interval is .00002 sec. The inference will be drawn that the sound originates in the median plane. Then substitute the receivers in the line joining the ears, one on each side of the head and the distance from ear to receiver being the same on both sides. With this arrangement the interval between the instants of arrival of the sound waves at the receivers will, with a sufficiently long base, surpass .00003 and the direction will not seem in the median plane but at one side. It thus becomes possible to judge directions with greater accuracy. This is not a fine spun theory merely, for the Germans put it into use during the war.

When the sound seems to originate in the median plane, the ear can note departures from this plane of about one degree, while well at the side a divergence of ten times as much is the smallest noticeable. When artificial receivers, such as microphones, are used to locate the sound source, it is not necessary to move the head of the observer. The line joining the instruments may be swung around or they may be maintained at rest while the length of path from ear to instrument is varied. There is an ambiguity in such measurements, since the same interval arises from sounds coming from the same direction either in front or behind. This is removed by swinging the arrangement through a right angle.

As sound travels 4.3 times as fast in water as in air, for the same accuracy of judgment the base in the liquid should be 4.3×21 centimetres long. The Hun submarines used such an arrangement to aid them in work.

Suggestions are made of applications of the great sensitiveness of the ear in perceiving direction. At the distant ends of two tubes of equal length are two telephone receivers actuated by the same microphone. Each tube leads to an ear. One tube has air, the other a gas in which the speed of sound is to be measured. The two sound waves, starting at the same time, will reach the ears at different times. By some compensatory method it can be made to appear that there is one sound in the median plane. The interval and, indirectly, the speed can be obtained from measurements of the compensation employed. Another application that has given good results in water is this. The problem is to measure the distance between two points. At each point place a sound receiver and join these to the ears by tubes of equal length. Let the source of sound give a tone of variable frequency, and for simplicity let it be somewhere on the line connecting the receivers. When the frequency is increased gradually, there will come a time when the ear perceives the sound in the median plane. In general this is at the instant when an impulse reaches one ear at the same time that the next following impulse arrives at the other ear. The distance from one point to the other equals the velocity of sound in the medium divided by the frequency of the source, that is by the number of impulses per second.

G. F. S.

NOTES FROM THE LABORATORY OF APPLIED SCIENCE, NELA RESEARCH LABORATORIES.*

AN INTERFERENCE THERMOMETER AND DILATOMETER COMBINED.

By M. Luckiesh, Director, L. L. Holladay, Physicist, and R. H. Sinden, Assistant.

[ABSTRACT.]

IT is a simple interference method of measuring a change of temperature and the corresponding expansion of three similar test specimens which are arranged symmetrically between two fused quartz plates. When the plates are illuminated normally with monochromatic light one set of interference fringes is produced by light reflected between the upper and lower surfaces of the upper quartz plate. After the quartz plate has been calibrated, the number of fringes that shift past a reference mark on the lower surface of the upper quartz plate provides a measure of the change in temperature of the quartz plate. In order to calibrate the quartz plate as a thermometer, a standardized thermocouple may be used to measure the change of temperature of the furnace and quartz plate. By changing the temperature of the furnace very slowly the lag of temperature between the thermocouple and the quartz plate may be reduced to a minimum. By making the test first with increasing temperature and then with decreasing temperature the total lag may be definitely determined.

The calibration may be checked by making an expansion test upon some substance whose expansion coefficient is accurately known. This may be done by the usual interferometer method by the addition of a second quartz plate. The specimens are placed between the two plates and a second set fringes is produced by the interference of light reflected between the lower surface of the upper quartz plate and the upper surface of the lower quartz plate. The number of these fringes that shift pass the reference mark gives a measure of the expansion of the specimens.

* Communicated by the Director.

THE COST OF DAYLIGHT.[1]

By M. Luckiesh and L. L. Holladay.

[ABSTRACT.]

DETAILED estimates have been made of the initial and annual costs of natural and artificial lighting. The initial net cost of equipment for natural lighting consists of the difference in cost of the building with and without windows (or skylights), the cost of real estate occupied by the light courts, and the cost of the extra heating system to supply the difference in heat losses from the windows and skylights and the wall replaced by the glass areas. The annual cost of natural lighting consists of interest upon the initial net cost, depreciation, cost of repairs, washing and extra fuel.

The initial cost of equipment for electric lighting consists of the cost of wiring, fixtures and portables; and its annual cost consists of interest upon the initial investment, depreciation, repairs, lamp renewals and electric energy.

In conclusion, it may be stated that the initial net cost of equipment for natural lighting is, for dwellings from 110 to 225 per cent. of the initial cost of the electric lighting; for apartments and hotels from 100 to 140 per cent.; for offices about 160 per cent.; and for art galleries 80 to 180 per cent. The annual cost of natural lighting is, for dwellings from 95 to 125 per cent. of the electric lighting; for apartments, hotels and offices, where electric lighting is freely used at all hours of the day, from 50 to 100 per cent.; and for art galleries about 135 per cent. of the electric lighting. The cost of artificial lighting used in the daytime to reinforce daylight has not been charged to natural lighting in the foregoing estimates. If this had been done the cost of daylight would have been appreciably greater in some cases.

SOME OPTICAL PROPERTIES OF RHODAMIN B.[2]

By A. Poritsky.

[ABSTRACT.]

THE paper comprises a study of various optical properties of solutions of fluorescent Rhodamin B in alcohol. It was found that

[1] To appear in the *Trans. I. E. S.*

[2] This work, begun in the Physical Laboratory of Cornell University, is to appear in the *Phys. Rev.*

within the studied region Beers' law and Lamberts' law of absorption are obeyed.

The wave-length where maximum energy in the fluorescence occurs shifts towards the infra-visible as the concentration is increased from 1 to 100; and remains there (583 mμ) for all further concentrations up to 10,000.

Previous exposure of concentrated solutions to intense light and heat shifts this wave-length toward the ultra-visible.

A film of dry rhodamin shows metallic reflection with one maximum fluorescence for concentrated solutions, and another lesser maximum at 540 mμ. The minimum at 550 mμ coincides with the maximum of absorption.

THE SCOPE OF SPECTROSCOPY.[3]

By Enoch Karrer.

[ABSTRACT.]

A GENERAL survey is given of some recent discoveries in spectroscopy and their application. It is pointed out how with the recent explorations in the extreme ultra-violet and the Röntgen regions, the electromagnetic spectrum has been almost completely mapped out in the sense that either the wave-lengths have been isolated, measured directly or indirectly, or some property of matter has been studied in reference to the radiation. There remains a small portion of the spectrum between the longest infra-red waves and the shortest Hertz wireless waves in which neither wave-length nor properties of bodies have been studied. No limit has been found to the shortness of X-rays and gamma rays.[4]

One of the most important advances recently made is the formulation between wave-length and voltage required to arouse radiation (*viz.*, λ V 12345). There are critical values of voltage at which radiation of certain wave-length appears without ionization, and others with ionization. Other ideas touched upon are, quantitative analysis by spectroscopy; constancy of spectra; number of spectral lines given by the elements; graphical representation of the atom.

From the standpoint of illuminating engineering the spectrum may be divided into three parts: the visible, the ultra-visible and the infra-visible.

[3] To appear in *Gen. Elec. Rev.*, July, 1922.

[4] If such a limit exists it would be of extremely great interest.

A Determination of the Number of Alpha Particles per Second Emitted by Thorium C of Known Gamma Ray Activity. A. G. SHENSTONE and H. SCHLUNDT. (*Phil. Mag.*, June, 1922.)—"Thorium C and its products produce, in the course of disintegration, alpha rays of ranges 8.6 centimetres and 5.0 centimetres in air, in the proportion of 65 to 35. At the same time they produce hard gamma radiation. Radium C similarly emits hard gamma radiation and alpha particles of range 6.96 centimetres and 3.8 centimetres, the latter, however, appearing in negligible numbers." Since the number of alpha particles emitted per sec. per mg. is known for Radium C, it is possible to compute the corresponding number for Thorium C by making a comparison of the number of scintillations caused in a minute on a zinc sulphide screen by the impact of the alpha particles from the two sources, the relative gamma ray activity being measured at the same time. The active deposit of thorium C was obtained by rotating a nickel disc for thirty minutes in a solution of radiothorium To provide radium C, radium emanation was allowed to decay overnight in a glass tube. The active matter deposited on the walls was dissolved in dilute hydrochloric acid, and a nickel disc stirred the solution for a few minutes.

To avoid making large counts of scintillations a rotating wheel with a slot on its circumference was interposed between the active material and the zinc sulphide screen. The alpha particles could reach the screen only through the slot. The control measurements for gamma ray activity were made with an electroscope. "Thorium C should fall to half value in 60.5 minutes and Radium C in 19.5 minutes. Actually we obtained decay curves giving periods of 60 to 61 minutes for thorium C and 19.5 to 20.2 for Radium C."

The mass of thorium C, which has the same activity as 1 mg. of radium and its products as measured by gamma rays that have in both cases traversed 3.3 mm. of lead, emits in one sec. 30,700,000 alpha particles of 8.6 cm. range.

G. F. S.

Viscosity of Air in a Transverse Electric Field. SATYENDRA RAY. (*Phil. Mag.*, June, 1922.)—Quincke found that both parallel and perpendicular to the electric lines of force the viscosity of liquids become greater in an electric field, "If polarization physically means an orientation of molecules or a kind of tidal distortion of the molecule, a change in the effective area of the cross-section and a consequent change in the viscosity with the electric field might be expected." To seek any change in the viscosity of air a transpiration method was used. The application of a field of 580 volts potential difference to two plates .31 millimetre apart failed to make even the change of a single second in the time of efflux, which was 9 minutes 39 seconds. There seems to be no change in the viscosity of air equal to as much as .3 per cent., owing to the application of the field.

G. F. S.

NOTES FROM THE RESEARCH LABORATORY EASTMAN KODAK COMPANY.*

THE DRYING AND SWELLING OF GELATIN.[1]

Preliminary Note by S. E. Sheppard and F. A. Elliott.

[ABSTRACT.]

THE theory of drying and swelling of gelatin gels is discussed, and observations are reported which make it more reasonable to believe that a so-called " case-hardening effect " is responsible for the maintenance of the original shape on swelling and drying. The initial stages of the drying process take place at edges and corners, thus creating a drier, rigid framework which guarantees the shape, and hence, submicroscopic structures inherent in gelatin are unnecessary to account for this phenomenon.

Talc and Soapstone in 1921. (*U. S. Geological Survey Press Notice.*)—The production of talc and soapstone in 1921 showed a great decline as compared with that in 1920. The quantity sold was the smallest since 1908 and was about 40 per cent. less than the average for the five preceding years.

The total quantity of talc and soapstone sold in 1921 was 126,000 tons, valued at $1,821,000, as compared with 211,000 tons, valued at $3,035,000, in 1920. This represents a decrease of 40 per cent. in both quantity and value. Vermont, which since 1917 has been the largest producer, maintained its position by producing 38 per cent. of the total quantity. New York produced 33 per cent. of the quantity sold, but for the first time took second place in the value of its product. Virginia, which produced 14 per cent. of the total, ranked next to New York in quantity, but for the first time led in the value of its output, owing to the fact that the soapstone industry in that State was not nearly so much affected as the ground talc industry, on which the other principal producing states depend.

The quantity of ground talc sold by producers in 1921 was 106,900 tons, valued at $1,181,000, as compared with 178,500 tons, valued at $2,143,000, in 1920. A canvass of the producers made to determine the quantity of talc consumed in 1921 by different industries shows that the paper industry used 38 per cent. of the total, and that the average value was about $10.60 a ton. Most of the supply was obtained from Vermont and New York. The paint industry, which

* Communicated by the Director.

[1] Communication No. 131 from the Research Laboratory, Eastman Kodak Company and published in *J. Amer. Chem. Soc.*, Feb., 1922, p. 373.

requires a high grade of talc, used 23 per cent. of the total. Nearly all the supply was obtained from New York, and the average value was about $14.10 a ton. The roofing industry consumed 18 per cent. of the total and drew its supply almost entirely from Vermont. The requirements for talc used in this industry are not exacting, as is shown by the average value, which was only $8 a ton. The rubber industry used a large quantity of talc for filler, and in 1921 consumed 9½ per cent. of the total. Vermont furnished most of the supply, which had an average value of about $9.50 a ton. The textile industry used about 4 per cent. as a filler for cotton cloth. The average value was about $9.40 a ton. Only 2½ per cent. of the domestic output was used for toilet powder, the demand for talc for that use having been supplied largely by imported material. California supplied most of the demand for domestic talc for this purpose, and the average value was $18.60 a ton.

R.

On the Elementary Quantity of Electricity. R. BAER. (*Ann. d. Physik*, No. 3, 1922.)—It is now generally recognized that electricity has an atomic structure. Upon this foundation is built the modern theories of atomic structure. Quantities of electricity cannot be changed continuously, but only by the addition or subtraction of one or more elementary quantities, just as the weight of a mass of water cannot be changed continuously but only by the addition or removal of one or more molecules. Moreover the body of physicists are agreed on the magnitude of the elementary quantity of electricity. It is 4.774×10^{-10} electrostatic units, for our own Millikan has measured it to a few tenths of a per cent. There has been, however, one protest registered against the validity of this conclusion. Ehrenhaft, in Austria, and his followers for a dozen years have been claiming to find a quantity of electricity, much smaller than Millikan measured, even perhaps as small as one two-thousandth of it. This is an important matter, and in science decisions are made by evidence and not by "the infallibility of the odd man" or even by a preponderance of votes as is the case when we go to the polls.

The whole question has been examined by the author of this paper, and he comes to the conclusion that the atomic structure of electricity rests on a firm foundation. The contrary results of Ehrenhaft and Miss Parankiewicz have arisen from their failure to make allowances for the Brownian Movements, and from the assumption of too large densities. "There is not the least evidence for the existence of quantities of electricity smaller than the charge of an electron." This is comforting especially for those who were trained at first to look on atoms as fine little billiard balls and have been subsequently constrained to adjust their conceptions to the belief that the atom is a miniature solar system and who were apprehensive lest still later the electron with its charge of electricity should turn out to be of an unexpected complexity.

G. F. S.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

FUNCTIONAL EVIDENCE OF THE PHYLOGENY OF THE NERVOUS SYSTEM AS SHOWN BY THE BEHAVIOR AND RESISTANCE OF THE DEVELOPING RAT TO STRYCHNINE.[1]

By E. W. Schwartze.

[ABSTRACT.]

THE reaction to strychnine of the very young rat is not unlike that shown by animals lower than mammals. This prototype reaction may be considered as functional evidence of the phylogeny of the nervous system. Very young rats also have a relatively high natal resistance to the action of strychnine which declines as the animals grow older until they reach a certain age. These observations agree with many scattering data on other animals, including man.

After the decline in natal resistance, the rat develops a post-natal resistance. Those animals for which sufficient data regarding the toxicity of strychnine exist showed this curious coincidence—a post-natal resistance to strychnine was developed in those animals in which the pyramidal tract is in the dorsal funiculus, while such resistance was not developed in animals having the pyramidal tract in the lateral funiculus. The data were not sufficient to permit analysis of cases where the pyramidal tract is in the ventral funiculus.

The observations suggest that strychnine tests would be useful, particularly in conjunction with other methods, in studying functional development of the central nervous system.

SEPARATION AND DETERMINATION OF SATURATED AND UNSATURATED FATTY ACIDS BY MEANS OF THE LEAD SALT-ETHER METHOD.[2]

By Walter F. Baughman and George S. Jamieson.

[ABSTRACT.]

THE percentages of saturated and unsaturated acids in a fatty oil and the iodine number of the unsaturated acid fraction are

* Communicated by the Chief of the Bureau.

[1] Published in *J. Pharmacol.*, **19** (1922), 273.

[2] Published in *Cotton Oil Press*, **6** (1922), 41.

more characteristic for many oils than some of the other values usually determined.

From a study of the lead salt-ether method for making this separation the authors have developed several modifications which it is believed increase the accuracy of the results.

This method is based on the solubility of the lead salts of the liquid unsaturated acids, oleic, lineolic, linolenic, and clupanodonic, in ether, in which the lead salts of the solid saturated acids, myristic, palmitic, stearic, arachidic, lingnoceric, etc., are practically insoluble. Satisfactory results cannot be obtained with cocoanut, palm kernel and similar oils which contain lauric, capric, caprylic and caproic acids because the lead salts of these acids are appreciably soluble in ether.

THE EFFECT OF NITRATES APPLIED AT DIFFERENT STAGES OF GROWTH ON THE YIELD, COMPOSITION, AND QUALITY OF WHEAT.[3]

By Jehiel Davidson.

[ABSTRACT.]

THE period between the resumption of growth of wheat in the spring and the time of heading was divided into three sub-periods. Each of three corresponding sets of plots received nitrates at one of these sub-periods. The results thus obtained show that:

1. The effectiveness of nitrates in increasing yields decreases consistently as the time of their application approaches the stage of heading.

2. The effectiveness of nitrates in increasing the protein content ($N \times 5.7$) of the grain increases as their effectiveness in increasing the yield decreases.

ANALYSES OF AUTHENTIC PEANUT OILS.[4]

By George S. Jamieson and Walter F. Baughman.

[ABSTRACT.]

IT is important for those interested in the fatty oil industry to know the limits of the variations in the chemical and physical characteristics of oils. The many results recorded in the literature

[3] Published in *J. Am. Soc. Agron.*, **14** (1922), 118.

[4] Published in the *Cotton Oil Press*, **6** (1922), 34.

show wide variations, but in many cases information on the treatment of the samples or on their authenticity is lacking. The composition of some may have been modified by storage. For these reasons the American Oil Chemists' Society requested the Bureau of Chemistry to determine the chemical and physical characteristics of authentic samples of the important commercial oils. Among the oils analyzed were 22 samples of authentic peanut oils collected during 1920, 1921, and 1922. The results show that there is a distinct difference between the values for oil from Virginia type peanuts and those for oil from Spanish type peanuts. The results for each type, however, are uniform. The averages of the results are given in the following table:

	Titer.	Refractive index at 20° C.	Specific gravity, 25/25°C.	Iodine number (Hanus).	Saponification value.	Saturated acids.	Unsaturated acids.	Iodine number of unsaturated acids.
						Per ct.	Per ct.	
All Samples	31.3	1.4691	0.9133	93.2	187.3	18.0	77.3	118.9
Variation:								
High	32.0	1.4720	.9148	98.2	188.4	20.6	79.5	125.6
Low	30.5	1.4670	.9123	89.0	186.6	15.3	74.2	109.0
Virginia type								
Samples				92.0		16.1	79.1	114.4
Variation:								
High				96.8		16.6	79.5	121.1
Low				89.0		15.3	78.7	109.0
Spanish type								
Samples				93.7		20.1	75.2	122.7
Variation:								
High				96.2		20.6	76.6	125.6
Low				90.1		18.7	74.2	120.2

A New Apparatus for the Demonstration of Gravitational Attraction. T. WULF. (*Physikal. Zeit.*, April 1, 1922.)—The Cavendish apparatus, consisting of a bar suspended by a thin wire and swinging in a horizontal plane furnishes a method of measuring very small forces. At the end of the bar is a metallic sphere which is attracted by a mass placed near it, with the result that the bar is turned from its original position. In the skilled hands of C. V. Boys and of Burgess, wonderfully accurate determinations have been made, but the instrument requires careful handling. Boys found it necessary to instal his experimental group in a cellar and was compelled to dedicate the hours of the early morning to it in order to avoid the upsetting effect of the traffic of London. The present experimenter is not desirous of making a new determination of the Gravitational

Constant, but he does want an apparatus that will perform well before a class and will not claim too much from the demonstrator.

His general plan is this. A large sphere is brought near to the sphere on the end of the horizontal beam. The force of gravitational attraction makes the beam turn to one side. It swings out to an extreme position and then turns back. At that instant the attracting mass is shifted to the other side of the sphere on the beam and hence accelerates the latter toward its first position. Whenever the beam comes to the end of its swing the attracting mass is shifted, with the result that the amplitudes of the vibration constantly increase. The damping effect of the air, however, comes in play so that eventually it is just counterbalanced by the force exerted by the attracting sphere and the amplitude stays constant. The exact maximum amplitude attainable can be fixed within narrow limits by running it up, on the one hand, and by letting it decrease from too great a value on the other.

Quartz fibres of ultra-microscopic diameters no longer are needed to suspend the horizontal pendulum, but brass wire .1 millimetre in diameter and 15 to 20 centimetres in length suffices. This has the further result that tremors and air currents cease to invalidate the observations. A demonstration apparatus, sitting on a table in front of a class, functions to the extent of producing a deflection of a metre on a scale two or three metres away.

G. F. S.

A New Interferential Method of Measuring the Apparent Diameter of Stars. A. DANJON. (*Comptes Rendus*, May 29, 1922.)—One objection to the Fizeau-Michelson method of determining the angular diameter of stars is that the two interfering beams must be 12 metres apart in order to serve for a star of apparent diameter equal to .01 sec. of arc. The proposal is made to use a Jamin interferometer. The sky is observed through the instrument and the star to be measured is seen upon the field of bright and dark bands. As it moves its brightness changes, becoming a minimum on a dark band and a maximum upon a bright band. The ratio of the two extreme intensities is measured and from this it is possible to calculate the angular diameter of the star. The whole determination, therefore, rests upon photometric measurements.

So far as purely laboratory tests go, the method has stood the trial well, but the prevalent bad weather in France during the past spring has kept the Strasbourg investigator from actual application to a star. Atmospheric agitation may prove an insuperable obstacle to success. The claim is made that for the measurement of Betelgeuse the two interfering beams need be but 10 centimetres distant from each other instead of 3 metres as hitherto. An attempt will be made to measure this star with a telescope having an aperture of only 16 centimetres, when Orion returns to our skies.

G. F. S.

NOTES FROM THE U. S. BUREAU OF MINES.*

PRESSURES OF PETROLEUM PRODUCTS AT ELEVATED TEMPERATURES.

By M. B. Cooke.

As a by-product of an investigation into the nature of "gum-forming" constituents of gasoline, the U. S. Bureau of Mines recorded data showing the pressure that may be developed in a still when gasoline or other oil is subjected to elevated temperatures. Samples of casinghead gasoline, motor gasoline, kerosene, and transformer oil were heated in a small steel bomb, the pressures developed were recorded by a gage, and temperature-pressure curves were made.

These curves show that petroleum products with a low boiling range—such as casinghead gasoline and some of the lighter motor gasolines—generate a higher pressure at a given temperature than water vapor. Petroleum products with a relatively high boiling range, such as kerosene and transformer oil, generate less pressure than water vapor at a given temperature. In general, the pressure generated by petroleum products, when subjected to elevated temperatures, varies inversely with the average boiling point of the product. The temperature curves, as well as the distillation range curves, are not parallel, owing to the carrying composition of the products. The complete report illustrated graphically may be obtained from the Bureau of Mines.

CAUSE AND PREVENTION OF DETERIORATION OF PORTLAND CEMENT.

By W. M. Meyers.

THE Bureau of Mines has completed an investigation of the cause of the deterioration of Portland cement during storage and transportation and suggests in a mimeographed report means for preventing such waste. French manufacturers recognize the deleterious effect of climatic conditions on Portland cement and endeavor to send their product direct to the point of consumption.

* Communicated by the Director.

The Bureau suggests two improvements in the practice of handling cement: (1) Storage and transportation of the cement in bulk; (2) storage and transportation of the cement in the form of unground clinker, grinding to be done at destination. The first method results in a decrease in hydration of cement, as the exposed surface is less. Shipment should be made in a tight closed car, and the cement at all points protected from moisture. The second method has the distinct advantage that the quality of cement produced from stored clinker is higher, on account of hydration of free lime in the clinker, and the grinding cost is lower because the mechanical disintegration of clinker during storage makes grinding easier. The report has a bibliography, and is now available.

PROPERTIES OF OKLAHOMA CRUDES.

By E. W. Dean, A. D. Bauer, M. B. Cooke, and C. R. Bopp.

As part of a comprehensive survey of American crudes, the United States Bureau of Mines recently completed a survey of Oklahoma crude oils. The Eastern, Rocky Mountain, Northern Texas, Northern Louisiana, Arkansas, and Kansas fields had been covered previously, and the data published.

The distillation of the Oklahoma crudes showed a narrow gravity range, mostly between 30 and 40° Baumé, with a minimum of 28.6° and a maximum of 52.1°. The average figure was 35.7°, which is noticeably higher than the average figure of 31.8° for Kansas crudes.

Sulphur content varied from 0.06 to 0.72—about one-half of the samples ranging from 0.1 to 0.2. The viscosity and pour tests showed a moderate degree of variation through the series, but none of the oils is exceptionally viscous.

To the refiner the most important property of crude petroleum is its content of gasoline and naphtha. The Oklahoma series makes a particularly favorable showing in this respect, as the average gasoline content is 27.6 per cent., some oils containing as much as 40 per cent.

Less than half of the Oklahoma crudes sampled require blending with volatile products from natural gas in order to make them a well-balanced motor fuel. The carbon residue varies from 3 to 13 per cent., mostly above 6 per cent., hence

most Oklahoma crudes could probably be made to yield a cylinder stock, some without special treatment, others with chemical treatment.

On the basis of relative gravities or viscosities of selected distillation fractions, practically all the Oklahoma crudes sampled are intermediate between the crudes of the paraffin-base type, such as Pennsylvania and West Virginia crudes, and those of the naphtha-base type, such as the California crudes, are exceptionally uniform in gravity.

The complete report on the Oklahoma crudes with tables of distillation results may be obtained in mimeographed form from the Bureau of Mines.

Barium and Strontium.—A report on Canada's resources recently issued by its Mines Branch, Department of Mines, shows that the hitherto exploited occurrences of barium and strontium minerals in Canada are all situated in Eastern Canada, and chiefly in Ontario and Nova Scotia. Barytes mining has had its greatest development in Nova Scotia, the important deposits at Lake Ainslie having furnished the bulk of the barytes produced in Canada. A number of small, scattered deposits occur in southeastern Ontario, but these are not considered of any great economic importance. In recent years, important bodies of barytes have been discovered in northern Ontario. Unfortunately some of the most promising deposits in this region are situated too far from a railroad to permit of their exploitation at the present time. Large deposits are also stated to occur in British Columbia near Spillimacheen, on the Kootenay Central railway, but no development of these occurrences has taken place.

With the exception of a few hundred tons produced in the Lake Ainslie district, Nova Scotia, there has been practically no output of barytes in Canada, for several years past. The cause for this would appear to be not lack of barytes, but the comparatively low price at which barytes has been selling. Barytes is produced very cheaply in Missouri, Georgia and Kentucky, the mineral occurring as lumps in clay and being dug out by hand (Missouri) or by steam shovel (Georgia). Canadian Barytes cost more to mine, and there is in addition, the remoteness of many of the deposits from the consuming centres to be considered. Also, Canadian vein barytes is often harder and more difficult to grind than the soft Missouri barytes.

Barytes finds its greatest use in the manufacture of paints and rubber goods. In these industries it is used either in the form of ground barytes or as lithopone, a product of barytes and zinc blende.

The only strontium mineral of importance occurring in Canada is the sulphate of strontium, celestite, which is only known in possible economic quantities in southeastern Ontario. The known deposits are

not very large, but, in one or two instances, are regarded as capable of successful exploitation, should an active demand for celestite arise. Most of the celestite consumed on the American continent is imported from England, and is used principally for the preparation of strontium hydrate which is employed in the refining of beet sugar. In the manufacture of fireworks strontium salts are used to produce red fire.

R.

Weather Forecasting. (*U. S. Department of Agriculture Press Service, Clip Sheet No. 210.*)—Instruction embracing a course in weather forecasting based on publications of the Weather Bureau and intended to increase the efficiency of pilots and improve the navigation of power boats generally, has recently been prepared by the United States Power Squadrons, a national association of power-boat owners, which was organized in 1915. This organization requires that applicants for membership shall pass an oral examination in piloting and chart work and encourages its members to study weather forecasting.

A pamphlet for which the Weather Bureau furnishes the authority, covering certain aspects of meteorology and forecasting, is issued to each member, and talks on weather forecasting are given from time to time to classes in different cities. Instruction to advanced classes in dead-reckoning and astronomical navigation includes questions on the laws of storms and general weather forecasting. The aim of the association is to raise the standard of skill in handling and navigating power boats, to coöperate with the Government in enforcing regulations relating to navigation, and to stimulate interest in activities tending to build up our merchant marine and navy.

R.

Fossil Flower in Rock.—Fossil flowers are such rare discoveries in the United States that the finding of a dogwood "flower" in a fragment of rock from the Glenrock coal field, Converse County, Wyoming, is of interest. Dr. F. H. Knowlton, a paleobotanist of the United States Geological Survey, identified the fossil as a species of *Cornus,* a typical genus of the dogwood family.

There are some forty or fifty living species of the genus *Cornus,* which is widely distributed over three continents of the Northern Hemisphere, and has one representative south of the Equator, a species in Peru. The leaves of more than twenty fossil species of Cornus have been found in North America, but the dogwood flower, just identified, is the first one yet found in the United States. Species of dogwoods first appeared in the middle of the Cretaceous, the geologic period in which dinosaurs lived; in other words the genus *Cornus* seems to have made its first appearance probably more than four million years ago.

R.

THE FRANKLIN INSTITUTE.

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BOOK NOTICES.

L'AZOTE: LA FIXATION DE L'AZOTE ATMOSPHÉRIQUE ET SON AVENIR INDUSTRIEL. By Louis Hackspill, University of Strasbourg. 261 pages, indexes, appendixes, 39 illustrations and many tables, 12mo. Paris, Gauthier, Villars et Cie. Price 14 francs, net.

The war awakened many of the greater nations to the importance of the nitrogen fixation problem. Scientists had been calling like prophets in the wilderness, but except in Germany, their voices had fallen on dull ears. This book is one of the encouraging instances of the appreciation of the danger of the exhaustion of one of the main sources of the world's supply of nitrogen compounds, the Chile nitrates. It is a very interesting and commendable treatise. Written for a wider public than the professional chemist, it does not enter into the physical chemistry as deeply as Creighton does in his paper in this JOURNAL, but it is evident that the author has searched the literature thoroughly and with full understanding, and he has the capacity to present his knowledge in a form intelligible to the general reader. The book is part of the second series of the Léauté Encyclopedia, and will be followed by others on applied science. The several works are not intended for the exclusive use of the trained expert, nor to furnish a complete statement of the subject treated, but to deal as occasion arises with the important features thereof. The dominant note is "selection."

English-speaking chemists are still wondering why their French brethren call nitrogen "azote." The term is not only highly inappropriate, but the general adoption of the other term would seem to leave no excuse for continuance. Our author, indeed, recognizes the incongruity of the title, for he says: "At present we can say that no godfather was worse inspired than Lavoisier when he gave the name azote to a substance so active in its chemical relations, and as necessary to the function of life. From this point of view, we may be reconciled to the fact that chemists nowadays do not know Greek." In terming nitrogen active the author, of course, refers to its many compounds, and not to the element in the free state. Even in this condition, however, it is not so distinctly poisonous as to justify the name which Lavoisier gave it. Fortunately, French chemists have given up writing "Az" as the symbol of the element, but they still retain the use of superiors, while all the rest of chemists use inferiors for designating numbers of atoms.

Turning to the text, it is found to contain an extensive and clear presentation of the many forms of nitrogen fixation that have been proposed. Beginning with a discussion of the food problem, especially as related to nitrogen supply, the warnings of Sir William Crookes are noted, and tables given to show how far his prophecies have been realized. The nitrogen cycle and the function of the modules in the roots of legumes are described, after which the properties of nitrogen and of certain nitrides are given. Separate chapters are devoted to the several processes that have been suggested for the purposes of fixation. The up-to-date character of the work is shown by the inclusion of a full account of the Bucher method of producing cyanides. A great deal of interesting matter is included in the description of the Haber process, which has filled such a striking and important rôle in the last few years. The

history is given in outline, and considerable information as to the details of the methods, but, as might be expected, many points are left without discussion, inasmuch as the German authorities have succeeded in keeping their important secrets very closely. It is noted, for example, in one of the appendixes, that Haber himself advised the German authorities against installing a plant in one of the possessions in the far East, although power sufficient for producing 100,000 tons of ammonium sulphate was available, his reason being that it would not be possible to obtain the technical skill for operating the works.

A short account is given of the explosion at Oppau. Mention is made of the statement by the Germans of the cause being the removal of a mass of ammonium nitrosulphate, but it is probable that if the experts know the cause they do not intend to tell. An account is given of the Claude process, which originating in France, is being now applied there. A feature of this is the use of very high pressure.

The book is neatly printed on good paper, has a fairly good index and numerous illustrations. A perusal of it will place the reader in possession of the present state of procedure on this very important phase of applied chemistry.

HENRY LEFFMANN.

PRACTICAL ELECTRICAL ENGINEERING; DIRECT CURRENTS. By Harry G. Cisin, M.E. 324 pages, 8vo. New York, D. Van Nostrand Company, 1922. Price, $2.00.

This is one of the non-mathematical books which deal in the simplest manner with electricity and magnetism, and are intended for the use of those who have not progressed beyond arithmetic. Such an effort as this is always hazardous and should be attempted by one who has had sufficient experience in teaching these subjects authoritatively to enable him properly to select and condense his material. This particular book, in addition to the disadvantage of the class to which it belongs, is further prejudiced by the verbose and often uncertain statement of its discussions. W. M. S.

THE PRINCIPLES UNDERLYING RADIO COMMUNICATION. Prepared by the Bureau of Standards for use of Signal Corps, U. S. Army. Second edition; revised to May 24, 1921. 619 pages, 12mo. Washington, Government Printing Office, 1922.

During the summer of 1918 the first edition of this book, containing then 355 pages, was prepared by Dr. J. H. Dellinger, physicist, Bureau of Standards, and a number of collegiate educators, then associated with the Bureau. It was intended for the training of the enlisted personnel of the Signal Corps for radio work; and has also been found useful as a text-book in schools and colleges.

The first third of this revised edition is occupied with the explanation of the elements of electricity, magnetism, and dynamo-electric machinery. The use of any, but the simplest, mathematics is studiously avoided, not only in this portion of the book, but throughout the subsequent chapters. However, the discussion makes frequent use of graphical methods which are generally excellent.

In the work proper the radio circuit is admirably studied, together with electrical oscillations and their decay, or damping. Both in radio and audio

transmission, and reception as well, the character of the decrement is of the greatest importance. While this matter receives full treatment, unfortunately the authors fail to mention that in addition to the logarithmical decrement it has recently been found that a linear, or proportional, decrement also exists, which, as it is made ascendant, increases the purity of wave-form, and freedom from harmonics injurious to transmission.

A book of this character should give especial attention to the nature and propagation of electromagnetic waves; but their discussion here is evasive and brief, almost to the point of confusion; but their excitation and control in the practice of radio communication is clearly and sufficiently discussed, though the description and principles of antenna construction might profitably have been enlarged to cover practice fully.

Decidedly the best section of the book is that devoted to the elements and radio practice of the electron tube. In this new art details of such apparatus are changing so rapidly that present forms need not be given more than passing notice; but it is essential to state thoroughly the principles of the operation of tubes. To this purpose the author of this section has admirably condensed a voluminous literature and given lucidity to many of its obscurities by well-developed graphical illustrations of the operation of these tubes.

So important at this time is the subject of radio communication, it is to be regretted that, at best, this book is an educational futility. Though its joint authorship is wholly competent, and its method is generally lucid—often unusually so—it must confuse the non-mathematical student; and annoy, through its evasions, those prepared to read it properly. The educational exigencies of the War might have excused its first composition; but in this revision the preparatory matter on electricity and magnetism should have been omitted, and the necessary mathematics have been employed which are required for a satisfactory discussion of the physics involved; while the practice could have been relegated to a handbook. The result would have been an authoritative text for military and general use on a subject whose increasing importance will soon rank it among the greatest applications of science. WILBUR M. STINE.

TESTING OF ELECTRICAL MACHINERY FOR NON-ELECTRICAL STUDENTS. By J. H. Morecroft and F. W. Hehre. Fourth edition, 220 pages, 8vo. New York, D. Van Nostrand Company, 1921. Price, $3.00.

This short course in the testing of electrical machinery is given by its authors at Columbia University to students of engineering other than electrical with the purpose of preparing them to deal with electrical details which may be intruded into their specific practice.

The subjects discussed in this course are: Direct and alternating current dynamos; motors, and their auxiliary operating appliances; electricity metres of the several prevalent types; storage batteries, and a suggestion of photometry. The method of the book is to preface or accompany the directions for laboratory testing with a considerable presentation of the electrical physics applied in the particular machine or apparatus.

This edition of the book has benefited by the scrutiny of its use for some ten years in its authors' laboratory, and as a result its discussions are generally conducted with force and clearness. But the informative portions are, under

necessity of brevity, so inadequate they must confuse the casually prepared student, and are not necessary for the capable one.

It is to be regretted that this class of book persists in electrical literature, as it will be a means to continue the superficial education of engineers, which has been too prevalent in our institutions. W. M. S.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 127. Aircraft Speed Instruments, by Franklin L. Hunt and H. O. Stearns. 38 pages, illustrations, quarto. Washington, Government Printing Office, 1922.

This report consists of three parts relating respectively to air-speed indicators, the testing of air-speed indicators and the principles of ground-speed measurement.

Part I discusses the different types of instruments which have been proposed for the measurement of air-speed and then gives detailed descriptions of most of the instruments, not only of American but also of British, French, Italian and German manufacture, which have reached the state of extensive use as service instruments. A statistical summary of the tests on air-speed instruments of the pressure type made at the Bureau of Standards during the recent war is given and also a short discussion of the altitude effect on air-speed indicators with a practical table of corrections.

Part II describes the methods of testing air-speed indicators used at the Bureau of Standards, together with the tolerances which service instruments should meet. Experimental data and sample reports showing the results of tests are also given.

Part III discusses the physical principles of ground speed measurement and the methods which have been devised for their practical application to the determination of the ground speed of aircraft.

Report No. 147. Standard Atmosphere, by Willis Ray Gregg. 11 pages, illustrations, quarto. Washington, Government Printing Office, 1922.

The need of a standard set of values of pressure, temperature and density at various altitudes is discussed and the desirability of adopting such values as are most in accord with actual average conditions is pointed out in order that corrections in individual cases may be as small as possible. To meet this need, so far as the United States is concerned, all free-air observations obtained by means of kites and balloons at several stations in this country near latitude 40° N. have been used, and average values of pressure, temperature and density, based upon those observations, have been determined for summer, winter and the year and for all altitudes up to 20,000 metres (65,000 feet). These values are presented in tables and graphs in both metric and English units; and in the tables of densities there are also included values of density for other parts of the world—more particularly for Europe. A comparison with these values shows that, except in the lowest levels, the agreement is very satisfactory. A further comparison with values of density determined from Toussaint's law of temperature decrease, $t = 15 - .0065z$, in which t is the temperature in °C., and z the altitude in metres, indicates very good agreement with those values up to 10 kilometres. It is therefore recommended that the United States adopt Toussaint's values of density up to 10 kilometres and the values presented in the tables for all higher altitudes.

Report No. 149. Pressure Distribution over the Rudder and Fin of an Airplane in Flight, by F. H. Norton and W. G. Brown. 9 pages, illustrations, plates, quarto. Washington, Government Printing Office, 1922.

This investigation was carried out by the Committee at the Langley Memorial Aeronautical Laboratory for the purpose of determining the loads which occur on the vertical tail surfaces in flight. The method consisted in measuring the pressures simultaneously at twenty-eight points on the rudder and fin by means of a recording multiple manometer. The results show that the maximum load encountered in stunting was seven pounds per square foot on the rudder and fin, and it is probable that this might rise to ten pounds per square foot in a violent barrel roll; but in steady flight the average loads do not exceed 0.6 pounds per square foot. The maximum load on the rudder and fin may occur at the same instant as the maximum load on the horizontal tail surfaces and the maximum normal acceleration. The torsional moment about the axis of the fuselage due to the rudder and fin may rise as high as 250 foot-pounds. The results obtained from this investigation have a direct application to the design of the rudder, fin, and fuselage.

PUBLICATIONS RECEIVED.

Leçons d'Analyse Fonctionelle professées au Collège de France, par Paul Lévy, Professeur a l'École Polytechnique, avec une préface de M. J. Hadamard, membre de L'Institut. 442 pages, 8vo. Paris, Gauthier-Villars et Cie., 1922. Price, 35 Francs.

Hydraulics with Working Tables, by E. S. Bellasis. Third edition, 348 pages, illustrations, 8vo. New York, E. P. Dutton and Company, 1922. Price, $8.00.

Mechanical Testing, by R. G. Batson, Associate of King's College, London, and J. H. Hyde, National Physical Laboratory. Volume 1: Testing of Materials of Construction. The Directly Useful Technical Series. 413 pages, illustrations, plates, 8vo. New York, E. P. Dutton and Company, 1922. Price, $9.00.

L'Azote. La fixation de l'azote atmospherique et son avenir industriel, par Louis Hackspill, Professeur a la Faculté des Sciences de l'université de Strasbourg. Encyclopedie Léauté. 271 pages, illustrations, 12mo. Paris, Gauthier-Villars et Cie., 1922. Price, 14 Francs.

Les Progrès de la Métallurgie du Cuivre, par Auguste Conduché, Professeur a la Faculté des Sciences de Rennes. Encyclopédie Léauté. 254 pages, illustrations, 12mo. Paris, Gauthier-Villars et Cie., no date. Price, 14 Francs.

Petroleum, Where and How to Find It, by Anthony Blum. 367 pages, illustrations, portrait, 12mo. Chicago, Modern Mining Books Publishing Company, 1922. Price, $2.00.

Les Axiomes de la Mécanique Examen Critique. Note sur la propagation de la lumière par Paul Painlevé, Professeur a l'École Polytechnique. 111 pages, 12mo. Paris, Gauthier-Villars et Cie., 1922.

Véritable Interprétation des Théories Relativistes, par Maurice Gandillot. 17 pages, illustrations, 12mo. Paris, Gauthier-Villars et Cie., 1922.

Le Principe de la Relativité et la Théorie d'Einstein, par M. Leon Bloch. 42 pages, 8vo. Paris, Gauthier-Villars et Cie., 1922.

National Advisory Committee for Aeronautics: Technical Notes, No. 101. Comparing maximum pressures in internal combustion engines, by Stanwood W. Sparrow and Stephen M. Lee. 3 pages, illustrations, quarto. No. 103. Simple formula for estimating airplane ceilings, by Walter S. Diehl. 4 pages, diagram, quarto. No. 104. Notes on aerodynamic forces—I. Rectilinear motion, by Max M. Munk. 13 pages, quarto. No. 105. Notes on aerodynamic forces—II. Curvilinear motion, by Max M. Munk. 10 pages, quarto. Washington, Committee, 1922.

Painting Cement Floors. ROY C. SHEELER. (*Textile World*, July, 1922, p. 69.)—It has become quite the custom to harden the cement floors in factories by working finely divided iron filings into the surface layer of the cement. Chemical treatment has also been resorted to. Both methods help to prevent dusting and powdering. But neither of these methods gives as good results as the application of the proper cement filler, and the right cement paint. This may seem strange, but it is nevertheless a fact.

If the pigment of the paint is carefully selected for its resistance to abrasion, if it contains a hardy, tough, rapid-drying water-resisting varnish which fills the pores with a hard glossy film, it will resist the rough wear of trucks and foot traffic as well as or better than, iron filings. Then, too, if there is a choice of colors, the floors can be greatly improved in appearance The other methods cannot be repeated, whereas the painting can be done as often as desired and is comparatively inexpensive.

The State system of distributing weather forecasts, warnings, and other information sent out by the Weather Bureau of the United States Department of Agriculture is being continually extended. There are 91 State broadcasting stations which send our weather reports now in operation, of which 20 are operated by leading newspapers. Negotiations are in progress with 33 additional stations, and most of these, which include 11 newspapers, are expected to be in operation in a short time.

R.

Bitter Milk.—LEROY S. PALMER, of the University of Minnesota (*Jour. Dairy Science*, 1922, v, 201–211), finds that the bitter milk of advanced lactation owes its bitterness to the action of a native enzyme lipase. This enzyme cleaves the fat of the milk quite rapidly even at fairly low temperatures, and liberates the lower volatile fatty acids such as butyric acid. These acids then impart a bitter flavor and a rancid odor to the milk. If the fresh milk be heated for a few minutes at a temperature of 75° C., the enzyme is inactivated, and the bitterness does not develop. J. S. H.

CURRENT TOPICS.

Grade Crossing to be Eliminated on Federal-Aid Highways. (*Eng. World*, June, 1922, p. 368.)—The grade crossings must go, and they will be eliminated wherever possible on the roads of the Federal-Aid Highway System, which will be built as a result of the passage of the Federal Highway Act. When the roads which form the primary or interstate system are constructed, no grade crossing will be allowed to remain that it is at all practicable to avoid. Every effort will be made to make the roads of the secondary system equally safe, but in this case it is recognized that elimination may not be practicable in all cases.

In making this announcement the Bureau of Public Roads, under whose supervision the fund is allotted and construction is undertaken, is putting into effect a policy which it has long advocated in principle, and whose adoption it has urged with increasing effectiveness upon state highway officials for sometime past. The policy is meeting with hearty coöperation on the part of the states, and the American Association of State Highway Officials by resolution has pledged its best efforts to coöperate to eliminate grade crossings on new construction.

In addition, the policy finds favor among the railroads, some of the leading carriers already having lent cheerful aid in avoiding the construction of more grade crossings.

Instead of grade crossings there will be constructed, wherever possible, in the future either a bridge or an underpass where roadway and railway intersect. Important roads, which now cross and recross railroad lines at grades, hereafter will be located entirely on one side of the railroad even though to do so may increase the cost of construction. State officials, realizing the need of eliminating grade crossings, have stated their desire to coöperate with the department in carrying out this plan.

Where crossings are unavoidable, or where local interests justify construction of highways to cross railroad lines, the road will be so located as to pass over the track or under it. In most instances of this sort the railroads bear one-half of the cost of building the bridge or underpass. R.

Diesel Electric Ferryboat for Service in San Francisco Harbor. (*Marine Engineering*, June, 1922, p. 377.)—The *Golden Gate*, which will be the first large automobile ferryboat in this country to be equipped with Diesel engine electric drive, is expected to begin operations in San Francisco Bay early in the coming summer. She will form part of a fleet of ferryboats operated by the Golden Gate Ferry Company, which will offer a fast service between Sausalito and San Francisco, to form a link between the northern and southern highway systems of the State of California.

The *Golden Gate* will have an overall length of 220 feet and a displacement length of about 207 feet. Her propelling equipment will consist of two 500-brake horsepower Werkspoor Pacific Diesel engines each directly connected to a General Electric Company 360-kilowatt, 250-volt, shunt-wound direct-current generator. The power from these generators will be delivered to two 750-horsepower, 500-volt, 145 to 180 revolutions per minute shunt-wound motors one on each propeller shaft. There will be a 35-kilowatt, 115-volt exciter direct connected to each engine generator and used to furnish power for lights, excitation and engine room and deck auxiliaries.

The boat will represent a radical departure in ferryboat construction, being the first double-ended one where each propeller will be driven separately. The most economical method of propelling such a boat is to have the majority of the power concentrated on the propeller that is actually driving it. Electric drive is the only way in which this can be satisfactorily accomplished and still use the same prime mover for both directions of travel, eliminating duplicate units for ahead and astern travel.

The flexibility of control which is a feature of Diesel engine electric drive has also been fully taken advantage of in this boat. She will be equipped with Ward Leonard control, with stations in both pilot houses as well as in the engine room. R.

Airplane to Locate Alaska's Lost Lakes.—Locating and photographing undiscovered lakes in the national forests of Alaska are the latest uses to which the airplane has been put, says the Forest Service, United States Department of Agriculture.

It has long been known that there are many lakes on the headlands and islands traversed by the inside passage between Seattle and Skagway that do not appear on any map. During the New York-Nome flight, made by Army aviators, lakes were frequently sighted which could not be found on the latest and most authentic maps of the territory. Tales of unknown water bodies are constantly being brought in by trappers and prospectors. Less than a year ago a lake four and a half miles long and one-half mile wide was discovered at the head of Short Bay. This lake has over 1000 acres of surface area and is less than one and a quarter miles from tidewater, yet because of the surrounding country's rough topography has remained unknown and unnamed.

Recognizing that many other of these "lost lakes" may be sources of valuable water power, the Forest Service has laid plans to map this no-man's land of the north by means of aerial photographs. A few days' flight, it is said, will be sufficient to cover the area with a degree of accuracy that would require many years and great expense to accomplish by ordinary methods.

The work, which has been approved by the Federal Power Commission, will be done by seaplane, flying from Ketchikan as a base.

R.

A Study in an American Desert.—One of the driest parts of the United States is what is called the Papago country, a region including about 13,000 square miles in southwestern Arizona, so called because it was long ago inhabited by the nomadic Papago Indians. This broad expanse of desert country, which lies between Gila River and the Mexican boundary, contains many groups of volcanic and other mountains separated by broad alluvial basins, which, though the rainfall is small and the temperature is high, sustain a scant growth of desert plants, including orchard-like groups of strange trees. Here the bold slopes of the mountains, the general absence of watering places, and the peculiar forms of the vegetation impress the traveler strongly with the majesty and the mystery of the desert, and excite his wonder as to the origin and history of the natural features.

A report on this region by Kirk Bryan has just been published by the United States Geological Survey, Department of the Interior, as Bulletin 730-B, under the title "Erosion and Sedimentation in the Papago Country, Arizona." The report describes the geology briefly as a setting for a consideration of the agencies that have produced the forms of the land and presents detailed conclusions as to the mode of origin of the desert landscape. The paper is illustrated with diagrams, views, and maps and should be of interest to all students of topography and physiotherapy, particularly those who are endeavoring to solve problems of erosion by wind and water in desert regions. R.

Sugar in Czechoslovakia (*Sugar*, June, 1922, p. 334.)—The total quantity of sugar exported from Czechoslovakia during the 1920–21 season amounted to 456,767 short tons compared with 375,351 short tons during the 1919–20 season. France provided the most important market, having taken 105,300 tons during the 1920–21 season compared with 166,229 tons during the 1919–20 season.

None of this sugar reached the United States during the 1920–21 season, although 3696 tons were marketed here during 1919–20.

Statistics of the total sugar production in Czechoslovakia for the 1921–22 season are not yet available, but it is reported that 3,830,492 short tons of sugar beets have been used, from which approximately 705,472 tons of raw sugar were produced. During the 1920–21 season the production of sugar in that country amounted to 790,614 tons. R.

Forty Thousand-Gallon Steel Tank Moved on Flat Cars. (*Public Works*, July 8, 1922, p. 29.)—A steel locomotive water supply tank of 40,000 gallons capacity, with a conical bottom terminating in a large diameter riser pipe and supported on four steel columns about 20 feet high, was recently jacked up 20 inches and transferred to temporary support on timber falsework, installed on the adjacent ends of the two standard gauge flat cars, heavily ballasted on the opposite ends, that were brought up on spur trucks close to the water tower on opposite sides. The cars were coupled together by chains

and the top-heavy empty tank was ballasted by several yards of gravel deposited on a temporary floor at the bottom of the riser pipe which cleared the rail.

The falsework tower was blocked and wedged to bearing on the inclined bottom of the tank, and the tops of the steel columns were guyed with tackles to the flat cars.

The tank was hauled two miles over the Canadian National Railway to Redpath Junction, British Columbia, without injury, care being taken to adjust the position of the cars when passing around curves by means of turnbuckles connecting the chains. R.

Dust Carried by Wind. (U. S. Department of Agriculture Press Service, Clip Sheet No. 211.)—Dust is carried by the wind for long distances, but not usually in quantities sufficiently large for identification. A sample of the dust that settled thickly on the decks of the Dutch steamship *Yildum* when 250 miles out at sea, in latitude 14–15° N., longitude 22° 10′ W.–21° 31′ W., was recently sent to the Weather Bureau of the United States Department of Agriculture by the captain of the vessel. The dust was undoubtedly blown from the Desert of Sahara, which is in approximately the same latitude as that reported by the *Yildum*. The Weather Bureau receives regular marine weather reports, such as that sent in by this vessel, from ships of 20 nationalities, which coöperate with the bureau in collecting and disseminating information about weather conditions at sea. Two days later the British steamship *Dundrennan* and the Dutch steamship *Hagno*, more than 1500 miles west of the *Yildum*, observed the same phenomenon, although the amount of dust was much smaller. R.

Peanut Oil. (*U. S. Department of Agriculture Press Service, Clip Sheet No. 210.*)—The manufacture of peanut oil has been stimulated a great deal in recent years because of the ravages of the cotton boll weevil in reducing cotton growing in certain sections. Peanuts are grown in place of cotton. Before 1914 very little of the oil was made, only 450,000 pounds being produced in 1912, but by 1918 the quantity turned out by crushers in this country was about 50,000,000 pounds. At the same time imports increased from 7,600,000 to 27,400,000 pounds.

R.

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